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AMERICAN JOURNAL of PHYSICS

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The Interaction of π Mesons with Atomic Nuclei*

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(Received April 27, 1953)

The interactions of π mesons with nuclei are reviewed and interpreted in terms of the Serber model of nuclear reactions at high energies. This involves introducing the concept of a mean free path for both meson scattering and absorption in nuclear matter. These quantities are discussed in relation to the relevant experimental data. A discussion of the "optical model" of nuclear scattering is also included.

I. INTRODUCTION

THE construction of accelerators in the 100-Mev energy range has made it possible to study nuclear reactions at energies large compared to nuclear binding.[1] At these energies the details of nuclear structure are expected to play a somewhat secondary role in the reactions, which in many respects appear to be considerably simpler than the lower-energy phenomena. The bombarding particles employed in such studies have been most frequently neutrons, protons, deuterons, or mesons. At present we shall be primarily concerned with the meson-induced reactions; however, the physical ideas used to describe these are essentially very similar to those for neutron and proton interactions.

As we are considering meson interactions with nuclei, we shall only briefly review the properties of π mesons. The mass of the positively and negatively charged π mesons (designated as π^+ or π^-) is about 275 electron masses (this corresponds to a rest energy of 140 Mev). The mass of the neutral π meson (designated as π^0) is 5 to 10 electron masses less than that of the charged mesons. These particles have no spin and are unstable, the mean life of the π^0 being (very roughly) 10^{-15} sec and that of the $\pi^\pm$ being about 2.5×10^{-8} sec. The π^0 usually decays into two γ rays and the $\pi^\pm$ into a $\mu^\pm$ meson and a light neutral particle, which is presumably a neutrino.

π mesons have been produced artificially by protons, neutrons, and by γ rays bombarding either free protons or atomic nuclei. In every case, positive, negative, and neutral mesons are produced (only if charge is conserved in the reaction, of course). The production from free protons and deuterons has been most useful in obtaining the characteristics of meson-nucleon interactions. To obtain meson beams of suitable intensity for meson scattering experiments the production from atomic nuclei has been employed. In Table I some typical cross sections for the production of mesons are summarized. In Fig. 1 a typical arrangement to obtain a meson beam from a cyclotron is shown.

* Supported in part by a grant from the National Science Foundation.
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[1] G. F. Chew and B. J. Moyer, Am. J. Phys. 19, 17 (1951).

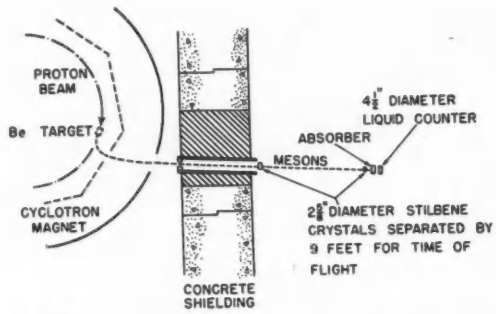

FIG. 1. Experimental arrangement used by Steinberger, *et al.* [reference (1d) of Table II] to get the meson beam out of the cyclotron and measure σ_{ab}. Mesons with 85-Mev kinetic energy have trajectories in the magnetic field of the cyclotron which pass through the slit in the concrete shielding. The electron and proton contaminations of the beam are eliminated from the meson beam with a time-of-flight velocity selector.

II. THE SERBER MODEL OF HIGH ENERGY NUCLEAR REACTIONS

The basic physical ideas for the description of high-energy nuclear reactions (energies of the order of 100 Mev or higher) were proposed by Serber.[2] He noted several aspects of high-energy reactions which are expected to be qualitatively different from those at lower energies. The first observation is that at sufficiently high energies the de Broglie wavelength of the bombarding particle is small compared to nuclear dimensions, which permits the position of the particle to be "localized" in the nucleus. Furthermore, the scattering cross sections are expected to be sufficiently small that the particle can penetrate a finite distance into the nucleus before interacting (which leads to the term "transparent nucleus" used by Serber). It was finally noted that the incident particle will have a velocity ($\simeq\frac{1}{2}C$ for a 100-Mev neutron or proton, where C is the velocity of light) much larger than that of a bound nucleon (neutron or proton) in the nucleus ($\simeq 0.1C$). This suggests that the incident particle can collide with a bound nucleon in a time so short that the latter will not have time to be influenced by the presence of its neighboring nucleons during the collision. Consequently, the collision is expected to be little modified by the nuclear binding of the struck particle and can be described as if it were the collision with a free neutron or proton (this conclusion has subsequently been verified quantitatively)[3] except for two effects. The first is due to the momentum distribution of the struck nucleon in the nucleus. This tends to "smear out" the restrictions imposed by energy and momentum conservation in collisions with free nucleons.[4] The second effect arises from the Pauli principle. The struck neutron (or proton) cannot recoil into a quantum state already occupied by another neutron (or proton) in the nucleus, which means that a certain region of phase space is not available to the system in the final state. This tends to reduce somewhat the scattering cross section of the incident particle with a bound nucleon. This reduction of the scattering cross section for a bound particle is expected to become less important as the energy of the incident particle increases.

TABLE I. Typical meson-production cross sections.

Meson charge	Incident particle	Target particle	Energy	$\times 10^{28}$ cm^2
+	p	p	340	2.4[a]
0	n	p	340	1.2[b]
−	p	n	340	0.1[c]
+	p	n	340	0.1[d]
+	γ	p	255	1.9[e]

[a] Reference 15.
[b] See, for instance, R. Hildebrand, Phys. Rev. **89**, 1090 (1953).
[c] The π^+/π^- ratio measured by Crother and Andre, Phys. Rev. **88**, 1426 (1952) for the production from deuterons has been used to deduce this cross section. In this estimate the deuteron binding and exclusion principle effects have been neglected.
[d] This is an indirect estimate. See, for instance, H. Wilson and W. Barkas, Phys. Rev. **89**, 758 (1953).
[e] J. Steinberger and A. S. Bishop, Phys. Rev. **86**, 171 (1952).

To summarize, we picture a fast particle as entering a nucleus and being scattered by one or more nucleons in the nucleus, the scattered amplitude for an individual collision being just that for a collision with a free nucleon.

Explicit calculations have followed one of two models which develop somewhat different aspects of the more general Serber model.

A. The Goldberger Model

Goldberger[5] has assumed that the nucleus is sufficiently large and the collision mean free path sufficiently long that the orbit of the incoming

[2] R. Serber, Phys. Rev. **72**, 114 (1947).

[3] This point has been discussed in detail by G. F. Chew and G. C. Wick, Phys. Rev. **85**, 636 (1952), and by G. F. Chew and M. L. Goldberger, Phys. Rev. **87**, 778 (1952).
[4] Cladis, Hess, and Moyer, Phys. Rev. **87**, 425 (1952); P. A. Wolff, Phys. Rev. **87**, 434 (1952).
[5] M. L. Goldberger, Phys. Rev. **74**, 1269 (1948).

(and struck particles) in passing through the nuclear matter can be defined in the sense of classical mechanics. That is, effects of wave interference are neglected. The development of the collision is then treated as a sort of cascade phenomenon.

B. The Optical Model

The optical model[6] is particularly concerned with wave interference. The nucleus is treated as an optical medium with a complex index of refraction n. The incoming particle wave is diffracted and partially absorbed in the medium.

If the incoming particles (we shall refer to them as "mesons," although our discussion of the optical model is quite general) have a momentum q directed along the z axis, the incoming wave is

$$\psi_0 = e^{ikz}, \tag{1}$$

where the wave number k is $q/\hbar$. Within nuclear matter the wave described by Eq. (1) is replaced by

$$\psi_i = e^{inkz}, \tag{2}$$

where n is the index of refraction. If this wave has traveled a distance D in the nucleus (see Fig. 2), then Eq. (2) must be modified, the phase of Eq. (1) being shifted by just $(n-1)kD$:

$$\psi_i = \exp i\{kz + (n-1)kD\}. \tag{2'}$$

The form of Eq. (2') assumes that there is negligible reflection of the meson wave at the nuclear surface, which receives an approximate justification on the supposition that the nucleus does not have a sharply defined boundary so the incoming wave undergoes a gradual transition from the external to the internal region.[6]

If $n = n_0 + i/(2k\lambda)$, where n_0 and λ are real, Eqs. (2) and (2') become

$$\psi_i = e^{in_0kz}e^{-z/2\lambda} \tag{3}$$

and

$$\psi_i = e^{ikz}e^{i(n_0-1)kD}e^{-D/2\lambda}, \tag{3'}$$

respectively. The quantity λ is seen to be the mean free path for absorption of the incoming beam within the nucleus, since the density of mesons varies as

$$\rho = |\psi_i|^2 = e^{-D/\lambda} \tag{4}$$

within the nucleus.

[6] Fernbach, Serber, and Taylor, Phys. Rev. **75**, 1352 (1949).

By "absorption" we mean either true absorption (as discussed in Sec. III) or inelastic scattering, which removes particles from the incident beam and thus represents a kind of absorption.

Equations (1) and (2) may be represented as the solutions to a Schrödinger equation with a complex potential V, which is assumed to be constant within and to vanish outside the nucleus:

$$\left[-\frac{\hbar^2}{2\mu}\nabla^2 + V\right]\psi = i\hbar\frac{d}{dt}\psi \tag{5}$$

$$= \frac{\hbar^2k^2}{2\mu}\psi, \tag{6}$$

where $\psi = \psi_0$ outside and $\psi = \psi_i$ inside the nucleus. The last step follows from noting that the energy

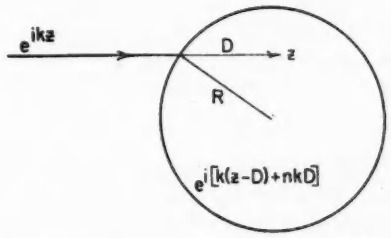

FIG. 2. To the right of the nucleus, the meson wave function is e^{ikz}. After the meson travels a distance D inside the nucleus, the phase of the wave function is changed by an amount $ik(n-1)D$.

of the meson outside the nucleus is

$$E = q^2/2\mu = (\hbar^2k^2)/(2\mu),$$

by Eq. (1), where μ is the mass of the meson. Substituting Eq. (2) into Eq. (6) and assuming the $V \ll \hbar^2k^2/2\mu$, we obtain the following relation between V and n:

$$V = -\frac{\hbar^2k^2}{2\mu}(n^2-1) \simeq -\frac{\hbar^2k^2}{\mu}(n_0-1) - i\frac{\hbar v}{2\lambda}. \tag{7}$$

[That is, we suppose the $(n^2-1) \simeq 2(n-1)$.] Here $v = \hbar k/\mu$ is the velocity of the incoming particle.

The potential V and the index of refraction n can also be approximately related to the scattering amplitudes for free (unbound) nucleons as follows. Let the scattering amplitude for the incident meson on a free proton be $f_p(\theta)$, where

θ is the angle of scattering. Then the wave function for the scattering is[7] (for large r):

$$\phi = e^{ikz} - (e^{ikr}/r) f_p(\theta).$$

Let $f_n(\theta)$ be the corresponding amplitude for scattering by a neutron. Then elementary dispersion theory gives[8]

$$V = (2\pi\hbar^2)/V_A\mu[zf_p(0) + (A-z)f_n(0)], \quad (8)$$

where $f_p(0)$ and $f_n(0)$ are the scattering amplitudes for $\theta = 0$ (i.e., scattering in the forward direction). The symbol A represents the mass number of the nucleus, and Z is its atomic number. $V_A = (4\pi/3)a_0^3 A$ and is the nuclear volume ($a_0 \simeq 1.4 \times 10^{-13}$ cm). By means of Eqs. (7) and (8) we are able to relate the scattering amplitudes to the index of refraction and to the complex potential V.[9]

To obtain the cross section for the incident particle absorbed by the nucleus, we first derive the continuity equation from the Schrödinger equation (5) and its complex conjugate,

$$[-(\hbar^2)/(2\mu)\nabla^2 + V^*]\psi^* = -i\hbar(d)/(dt)\psi^*. \quad (5')$$

We multiply Eq. (5) on the left by ψ^* and Eq. (5′) by ψ and subtract the resulting Eq. (5′) from Eq. (5), with the result that

$$-\frac{\hbar^2}{2\mu}[\psi^*\nabla^2\psi - \psi\nabla^2\psi^*] + \psi^*\psi(V - V^*) = i\hbar(d/dt)(\psi^*\psi). \quad (9)$$

Defining, as usual,

$$\mathbf{j} = \frac{\hbar}{2\mu i}[\psi^*\nabla\psi - \psi\nabla\psi^*], \qquad \rho = \psi^*\psi, \quad (10)$$

as the current vector and density of the incident particles, Eq. (9) becomes

$$\nabla\cdot\mathbf{j} + (\partial\rho/\partial t) = (2/\hbar)(\mathrm{Im}(V)\rho), \quad (11)$$

where $\mathrm{Im}(V)$ means the "imaginary part of V."

Equation (11) is the continuity equation for the incident particle inside the nuclear medium. [Its derivation differs from conventional discussions (see reference 7, p. 24, for instance) only in that here V is a complex rather than a real quantity.] From Eq. (7) we see that

$$\mathrm{Im}(V) = -(\hbar v)/(2\lambda). \quad (12)$$

The negative of the right-hand side of Eq. (11) is obviously to be interpreted as the rate of absorption of the incident particles per unit volume within the nucleus. The total rate of absorption W from the entire nucleus is the integral of this over the nuclear volume V_A;

$$W = -(2/\hbar)[\mathrm{Im}(V)]\int_{V_A}\rho d^3x. \quad (13)$$

From Eq. (4) we see that the density ρ at a depth $D(\mathbf{x})$ within the nucleus is

$$\rho = \exp\{-D(\mathbf{x})/\lambda\}, \quad (14)$$

as can also be seen from Fig. 2.

The absorption cross section σ_{ab} is obtained from W by dividing by the flux v of incoming particles. Substituting Eqs. (14) and (12) into Eq. (13) we have

$$\sigma_{ab} = \frac{W}{v} = \frac{1}{\lambda}\int_{V_A} e^{-D(\mathbf{x})/\lambda} d^3x. \quad (15)$$

Writing $V_A = (4\pi R^3)/3$, the above integral can be easily evaluated to give

$$\sigma_{ab} = \pi R^2\left\{1 - \tfrac{1}{2}\left[1 - \left(1 + \frac{2R}{\lambda}\right)e^{-(2R)/\lambda}\right]\left(\frac{\lambda}{R}\right)^2\right\}. \quad (16)$$

For $R = a_0 A^{\frac{1}{3}} \gg \lambda$, this reduces to

$$\sigma_{ab} = \pi R^2 = \pi a_0^2 A^{\frac{2}{3}}, \quad (16')$$

the latter form giving the A dependence of σ_{ab}. As given by Eq. (16′), σ_{ab} is, of course, just the geometrical area of the nucleus. This represents the maximum value of σ_{ab} and has important consequences for our subsequent analysis of the experimental cross sections, since we shall find that most of the measured values of σ_{ab} are approximately "geometrical."

The angular distribution of the elastically scattered particles may also be easily obtained

[7] L. I. Schiff, *Quantum Mechanics* (McGraw-Hill Book Company, Inc., 1949).

[8] E. Fermi, *Nuclear Physics* (University of Chicago Press, Chicago, 1950), revised edition, p. 201.

[9] A more formal derivation of these results has been given by K. M. Watson, Phys. Rev. 89, 575 (1953). It is also shown here that these results hold when the meson has a relativistic velocity. In this case, the μ of Eqs. (7) and (8) is replaced by the rest energy plus kinetic energy (divided by C^2).

from the integral equation[7] corresponding to Eq. (5),

$$\psi = e^{ikz} - \frac{2\mu}{4\pi\hbar^2}\int G(\mathbf{x},\mathbf{x}')V\psi(\mathbf{x}')d^3x'. \quad (17)$$

The Green's function $G(\mathbf{x},\mathbf{x}')$ satisfies the equation

$$(\nabla^2+k^2)G(\mathbf{x},\mathbf{x}') = -4\pi\delta(\mathbf{x}-\mathbf{x}'). \quad (18)$$

If we require that for large $|\mathbf{x}-\mathbf{x}'|$ the Green's function represents only outgoing "wavelets," the second term in Eq. (17) will be the scattered wave. Inserting the solution of Eq. (18) for large $|\mathbf{x}-\mathbf{x}'|$ into Eq. (17) we obtain

$$\psi_{r\to\infty} = e^{ikz} - \frac{2\mu}{4\pi\hbar^2}V\frac{e^{ikr}}{r}\int_{V_A} e^{-i\mathbf{x}'\cdot\mathbf{k}'}\psi(\mathbf{x}')d^3x'. \quad (19)$$

(The integral is taken over the nuclear volume only, since V has been assumed to be constant within the nucleus and to vanish outside.) In Eq. (19) $\mathbf{k}'$ has the magnitude of k and the direction of the scattered wave. The scattering amplitude $f(\theta)$, which is the coefficient of $[-e^{ikr}/r]$ in the second term of Eq. (19), is obtained when we substitute ψ_i from Eq. (2′) into the integral. Since $\mathbf{k}$ is parallel to the z axis, $kz' = \mathbf{k}\cdot\mathbf{x}'$, and thus

$$\psi_i = \exp\{i[\mathbf{k}\cdot\mathbf{x}' + (n-1)kD(\mathbf{x}')]\}.$$

Then,

$$f(\theta) = \frac{2\mu V}{4\pi\hbar^2}\int_{V_A} e^{-i\mathbf{k}'\cdot\mathbf{x}'}e^{i[\mathbf{k}\cdot\mathbf{x}'+(n-1)kD(\mathbf{x}')]}d^3x'.$$

The integral appearing in this expression for $f(\theta)$ can be evaluated easily if cylindrical coordinates with the origin at the center of the nucleus are used. Then $D = (R^2-\rho^2)^{\frac{1}{2}}+z$, where the z axis is taken to be in the direction of $\mathbf{k}$, $(R^2-\rho^2)^{\frac{1}{2}}$ is the maximum value of z, and ρ is the distance from the z axis to $\mathbf{x}'$. Assuming that $\mathbf{k}$ and $\mathbf{k}'$ have approximately the same direction,

$$(\mathbf{k}-\mathbf{k}')\cdot\mathbf{x}' \simeq k\rho\sin\theta\sin\phi.$$

The integration over the azimuthal angle ϕ can be performed, since

$$\int_0^{2\pi}\exp(ik\rho\sin\theta\sin\phi)d\phi = 2\pi J_0(k\rho\sin\theta).$$

Then, after integrating with respect to z we have, on expressing V in terms of n by Eq. (7),

$$f(\theta) = -ik\int_0^R [1-\exp\{2i(n-1)k[R^2-\rho^2]^{\frac{1}{2}}\}] \times J_0(k\rho\sin\theta)\rho d\rho. \quad (20)$$

The differential scattering cross section is[7]

$$\frac{d\sigma_d(\theta)}{d\Omega} = |f(\theta)|^2. \quad (21)$$

Since n has a positive imaginary part, the exponential term in Eq. (20) is small and may be neglected for *large* nuclei (large values of R). The integral may then be immediately evaluated

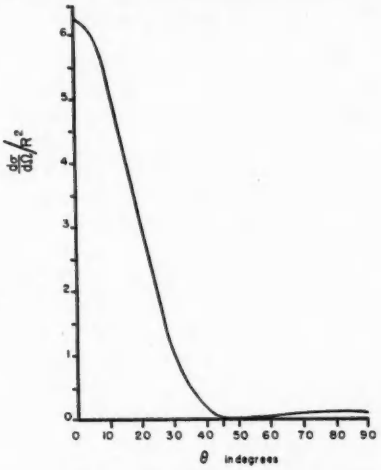

FIG. 3. Elastic differential cross section calculated for $kR=5$.

to give the approximate expressions

$$f(\theta) \simeq -iRJ_1(kR\sin\theta)/\sin\theta, \quad (20')$$

and

$$\frac{d\sigma_d(\theta)}{d\Omega} \simeq (\pi R^2)^2\left[\frac{J_1(kR\sin\theta)}{\sin\theta}\right]^2. \quad (21')$$

A plot of $d\sigma_d/d\Omega$ is given in Fig. 3.

These results were presented in reference 6 and used in the study of the scattering of fast neutrons by nuclei. The differential cross sections in Eqs. (21) and (21′) are of the form expected for optical diffraction, which has led to the term "diffraction scattering" as applied to the elastic scattering of fast particles by atomic nuclei.

The cross sections given in Eqs. (16) and (21) are approximate, since we have not satisfied the

continuity equation at the nuclear surface. A more careful treatment would involve solving the Schrödinger equation (5) exactly, matching logarithmic derivatives of the nuclear wave functions at the nuclear surface.[10]

In the following we shall use aspects of both the Goldberger and opticals models in discussing the interactions of π mesons with atomic nuclei. We shall suppose that the meson interacts with just one (or two) nucleons at a time. We shall discuss the mean free path for interaction and use this to interpret experimental studies of meson-nucleus reactions.

III. THE ABSORPTION OF π MESONS WITHIN ATOMIC NUCLEI

It is known that π^- mesons stopped in material substance give rise to energetic nuclear stars.[11,12] From the energy released in these events it is inferred that the entire rest energy of the meson is converted into nuclear excitation energy. The following mechanism has been proposed for this process.[13] The meson is slowed to an energy of a few kilovolts by collisions with orbital electrons and is eventually captured into a Bohr orbit of its own about a nucleus. It falls to lower orbits by imparting energy to orbital electrons and then by radiation until it reaches one of the very lowest Bohr orbits. It is then close enough to be found with appreciable probability within the nucleus and is directly absorbed, its rest energy (of about 140 Mev) appearing as nuclear excitation. In contrast to this, π^+ mesons (unless they are absorbed in flight) decay rather than are absorbed when stopped in matter. This has the obvious interpretation that the stopped π^+ meson will never be found with appreciable probability to be near a nucleus, since it is repelled rather than attracted (as was the π^-) by the Coulomb field of the latter.

On the other hand, both π^- and π^+ mesons may be absorbed in flight. This results from the fact that an atomic nucleus has a finite size so that the meson has a finite chance of passing through at least one nucleus before being brought to rest. As we shall see, experimental evidence indicates that a meson which once enters a nucleus will very likely be absorbed before it can get out. (We must, of course, qualify this statement, since the interaction has been studied only to meson energies of about 100 Mev and less.) This means that the absorption cross section will be nearly "geometrical" [see Eq. (16′)].

We shall be particularly concerned with the mechanism of mesonic absorption and with the relation of this to meson production. The requirements of energy and momentum conservation imply that a meson cannot be absorbed by a single neutron or proton without emission of other particles (in this case a γ ray is usually emitted). Thus the simplest nucleonic system in which pure absorption can occur is the deuteron, and here two reactions have been observed.

$$\pi^+ + D \text{—} P + P \qquad \text{(a)}$$

$$\pi^- + D \rightarrow N + N. \qquad \text{(b)}$$

Reaction (a) has been measured in considerable detail by Durbin, Loar, and Steinberger.[14] A rough semi-empirical formula for the cross section for this reaction in the center-of-mass coordinate system is

$$\frac{d\sigma_a}{d\Omega} \simeq \left(\frac{q}{\mu c}\right)^2 \left(\frac{c}{v_\pi}\right) \cos^2\theta [1.2 \times 10^{-27} \text{ cm}^2]. \qquad (22)$$

Here μ is the mass of the meson, q is its momentum, and v_π is its velocity; θ is the angle between the direction of the incident meson and that of either of the recoil protons. Equation (22) seems to be a fair approximation for meson energies between about 10 and 50 Mev. Available experimental and theoretical information concerning reaction (b) suggests that (except for Coulomb effects) its cross section is very nearly equal to that of reaction (a).

Reaction (a) is just the inverse of the process

$$P + P \text{—} \pi^+ + D, \qquad \text{(A)}$$

which had been previously observed.[15] If we de-

[10] This has been done, for instance, by Byfield, Kessler, and Lederman, Phys. Rev. **86**, 17 (1952), in the analysis of meson scattering from carbon.

[11] W. B. Cheston and L. J. B. Goldfarb, Phys. Rev. **78**, 683 (1950); Menon, Muirhead, and Rochat, Phil. Mag. **41**, 583 (1950); F. Adelman, Phys. Rev. **85**, 249 (1952).

[12] A highly excited nucleus usually emits several neutrons and protons in the process of returning to its ground state. In a cloud chamber or photographic plate the protons leave visible tracks all originating from a common point—thus the designation "star."

[13] E. Fermi and E. Teller, Phys. Rev. **72**, 399 (1947).

[14] Durbin, Loar, and Steinberger, Phys. Rev. **83**, 646 (1951).

[15] M. Whitehead and C. Richman, Phys. Rev. **83**, 855 (1951); Cartwright, Richman, Whitehead, and Wilcox, Phys. Rev. **91**, 677 (1953).

note the cross section for this process by $d\sigma_A/d\Omega$, the *principle of detailed balancing*[16] gives a relation between this cross section and the cross section for reaction (a). [Equation (23) is expressed in the center-of-mass coordinate system]:

$$(d\sigma_a/d\Omega)=(4/3)(p^2/q^2)(d\sigma_A/d\Omega). \quad (23)$$

Here p is the momentum of one of the protons and q is that of the meson. It is, of course, necessary that the two cross sections related by Eq. (23) be compared at the same total energy. Measured values of $(d\sigma_a/d\Omega)$ and $(d\sigma_A/d\Omega)$ have been found to be in quite satisfactory agreement with Eq. (23).

Reactions and their inverses [such as (a) and (A)] occur frequently in meson phenomena. For this reason the principle of detailed balance is very useful, since it makes it necessary to observe just one of the two reactions [the inverse being given in terms of the measured one by a formula such as that of Eq. (23)]. For instance, the inverse to reaction (b) is not amenable to direct experimental measurement (since this would involve bombarding free neutrons by neutrons); however, (b) itself is. Again, the reaction

$$N+P\rightarrow\pi^0+D \quad (C)$$

has recently been observed.[17] The inverse of reaction (C) cannot be directly measured, since the π^0 meson has too short a lifetime.[18]

Having seen that the absorption of mesons in deuterium is closely related to meson production in nucleon-nucleon collisions, we naturally are interested in the relation of these phenomena to absorption in nuclei heavier than the deuteron. Here again we are led to expect, on the basis of both theory and experiment, that the basic mechanism is much the same as in deuterium. To see this, we consider a simple model. Suppose a slow π^- meson (we assume that it is slow to simplify the arguments) enters a nucleus and is absorbed by a proton (it cannot be absorbed by a neutron because of charge conservation). Now energy conservation is violated by an amount $\Delta E\simeq 140$ Mev, the rest energy of the meson. To conserve energy the proton (which is now a neutron) must scatter against another nucleon. The two nucleons will emerge from this scattering in roughly opposite directions, since the total momentum is small, and with an energy of about

$$p^2/2M\simeq\Delta E/2=70 \text{ Mev} \quad (24)$$

apiece. Here M is the mass of the nucleon. Between the time of the absorption and the scattering events energy conservation is violated by roughly μc^2. This means that the absorption and scattering must be separated by a very short time interval; or that the two nucleons must be able to "find each other" to scatter immediately after the absorption takes place. The absorption probability is thus expected to be *proportional* to the probability P that these two nucleons can "find each other." The impact parameter associated with a momentum transfer p (Eq. (24)) is roughly

$$d=\hbar/p=\hbar/c\sqrt{M\mu}\simeq 0.39a_0, \quad (25)$$

where $a_0\simeq\hbar/\mu c=1.4\times10^{-13}$ cm, is the mean separation of nucleons in the nucleus. The probability P of the nucleons "finding each other" is then the probability that they were at a distance d from each other when the absorption occurred. The absorption in deuterium will be similar, except that the probability, P_D, of the neutron and proton being at a distance d from each other in the deuteron is expected to be different from P, which refers to a heavier nucleus. Hence the absorption rate per proton in a heavier nucleus is expected to differ from that in deuterium by the ratio

$$\Gamma\equiv P/P_D. \quad (26)$$

We therefore write the cross section *per proton* for capture of a π^- meson within a heavier nucleus as

$$\sigma^{(-)}=\Gamma\sigma_b, \quad (27)$$

where σ_b is the cross section for reaction (b) (i.e., in deuterium). The mean free path λ_a for absorption in a nucleus is then

$$(1/\lambda_a)=(z/V_A)\sigma^{(-)}, \quad (28)$$

where z/V_A is the density of protons in the nucleus. Experimental evidence indicates that the absorption of π^+ mesons is very nearly the same as that for π^- mesons, so we take λ_a to be the

[16] R. C. Tolman, *The Principles of Statistical Mechanics* (Oxford University Press, London, 1938), p. 521; J. M. Blatt and V. F. Weisskopf, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 530.

[17] R. Hildebrand, Phys. Rev. **89**, 1090 (1953).

[18] As mentioned in the Introduction, the π^0 meson decays into two γ rays with a lifetime which is not much greater than 10^{-15} sec.

mean free path for absorption of π^+ mesons also (we shall suppose that $z \simeq A/2$ for the calculation of λ_a). Such evidence as exists suggests that the mean free path for absorption of π^0 mesons is again about λ_a.

Since Γ, as given by Eq. (26), is independent of the energy of the meson, it enters just as an undetermined numerical factor into Eq. (28). By our assumption that $\sigma_a \simeq \sigma_b$ we can use Eq. (22) to determine the energy dependence of λ_a.

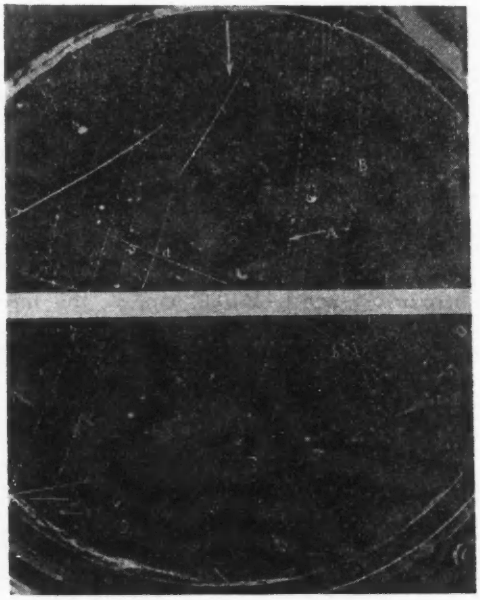

FIG. 4. Photograph taken by Eyfield *et al.* (reference 10) in which a π^+ meson A is absorbed by a carbon nucleus from which 2 energetic protons, b and d, are emitted in approximately opposite directions. A second meson B is elastically scattered through an angle of 32°.

Equation (27) must clearly oversimplify the complexity of the absorption in a nucleus.[19] Nevertheless, it is very likely a fair approximation for the mean free path and thus can be a useful guide in interpreting the experimental phenomena. Experimental evidence in favor of the model for the absorption just discussed has been obtained by Bernardini and Levy,[20] and by Byfield, Kessler, and Lederman.[10] They have observed in photographic plates two fast protons emerging from a nucleus which has just absorbed a π^+ meson. The frequency with which this is observed as well as the direction and energies of the protons are consistent with the direct absorption by just two nucleons, as discussed above. Such an event is shown in Fig. 4.

[19] A more formal and complete discussion of this model has been given by Brueckner, Serber, and Watson, Phys. Rev. 84, 258 (1951).

[20] Bernardini and Levi, Phys. Rev. 84, 610 (1951).

IV. MESON SCATTERING

The scattering of mesons by protons and deuterons has received considerable study. In Fig. 5 are given the total cross sections for mesons scattered by protons. The data on scattering by deuterons (which permit an estimate of the scattering of mesons by neutrons) are consistent with the equality of the cross sections for

$$\pi^+ + P \rightarrow \pi^+ + P$$

and

$$\pi^- + N \rightarrow \pi^- + N,$$

etc. If we denote (for a given charge state of the meson) the cross sections for scattering from neutrons and protons by σ_N and σ_P, respectively, then the mean free path for scattering in a nucleus of atomic number Z and mass number A is

$$(1/\lambda_s) = (1/V_A)[z\sigma_P + (A-z)\sigma_N]. \qquad (29)$$

(Here, as before, V_A is the volume of the nucleus.) This expression for λ_s is only approximate, however, since nuclear binding will modify the free nucleon cross sections, σ_N and σ_P. The exact expression for λ_s should therefore be expressed with σ_N and σ_P in Eq. (29) replaced by modified cross sections, σ_N' and σ_P'. The values of σ_N' and σ_P' are difficult to estimate reliably, but are expected to be roughly equal to σ_N and σ_P, except at rather low energies (for such energies, absorption seems to predominate over scattering, as will be seen). We shall suppose λ_s to be the same for the three charge states of the meson, in agreement with the available experimental data.

The resultant mean free path λ for either inelastic scattering or absorption is therefore

$$(1/\lambda) = (1/\lambda_s) + (1/\lambda_a), \qquad (30)$$

where λ_a is given by Eq. (28). The mean free path λ is the quantity which appeared in Eq. (3) and elsewhere in Sec. II in the discussion of the optical model. Thus, for the discussion of the

elastic (diffraction) scattering by the nucleus, as well as for the total cross sections, one need not distinguish between true absorption and inelastic scattering by the nucleus. Experimental measurements of these phenomena can therefore suffice to determine only λ—not λ_s and λ_a individually.

In principle, λ_s and λ_a could be determined individually from a detailed study of the inelastic scattering (i.e., the separation of inelastic scattering and absorption). This is not a simple thing to do, however, so we shall attempt to analyze the experimental data using Eq. (29) and the observed cross sections σ_N and σ_P for λ_s.

One interesting qualitative feature of the relative values for λ_s and λ_a can be seen from their respective energy dependences as derived from Eqs. (22), (27), and (28), and from Eq. (29). Combining the first three of these equations, we find that

$$1/\lambda_a \sim q^2/v_\pi,$$

where q is the momentum and v_π is the velocity of the meson. This equation is expected to be roughly valid for energies to about 50 or 60 Mev (and perhaps higher). The data in Fig. 5 imply that the variation of λ_s with energy is

$$1/\lambda_s \sim q^4,$$

which probably holds to energies well above 100 Mev. It is evident that λ_s^{-1} increases with the kinetic energy of the meson more rapidly than does λ_a^{-1}. We may consequently expect absorption to predominate at low energies and scattering at high energies. From the evidence presented in the next section it appears that this is the case.

V. MESON SCATTERING AND ABSORPTION IN NUCLEI

Cloud chambers, photographic emulsions, and counters have been used to study the scattering and absorption of charged π mesons by atomic nuclei. For the measurement of the total absorption cross section [i.e., σ_{ab}, as given by Eq. (16)] counters have been most frequently used. A typical experimental arrangement for the measurement of σ_{ab} is shown in Fig. 1. The number of mesons entering the target is counted by the first set of counters. The number of mesons passing directly through the target is counted by the second set of counters. The difference between these two counts gives the number of mesons absorbed or inelastically scattered, when corrections are made for the finite solid angle of the second set of counters with respect to the target.

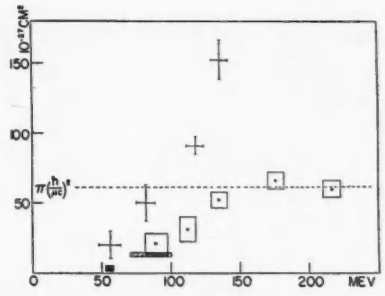

FIG. 5. Total cross sections of negative pions in hydrogen (sides of rectangle represent the error) and positive pions in hydrogen (arms of cross represent the error). The cross-hatched rectangle is the Columbia result [reference (1d) of Table II]. The black square is the Brookhaven result and does not include charge exchange scattering [see Schutt, Fowler, Miller, Thorndike, and Fowler, Phys. Rev. **84**, 1247 (1951)]. All other points were obtained by Anderson, Fermi, Lang, and Nagle, Phys. Rev. **85**, 936 (1952).

Studies which separate true absorption from inelastic scattering have been made using cloud chambers and photographic plates. In such experiments the tracks of individual mesons are observed, the scattering appearing as a deflection of the track. (If the meson gives up its charge to the nucleus and is emitted as a π^0, then it leaves no visible track. This type of scattering is known as "charge exchange scattering.") A measurement of the energy of the meson before and after scattering serves to determine whether the scattering has been elastic or inelastic. The photographs of Figs. 6 and 7 illustrate elastic and inelastic scatterings, respectively.

Most of the gross features of the experimental cross sections can be easily explained in terms of the optical model, as developed in Sec. II. Reference to Eq. (16) shows that the absorption cross section σ_{ab} can be calculated once the energy-dependent mean free path λ is known. Equation (30) expresses λ in terms of λ_s and λ_a, which in turn are given by Eqs. (28) and (29). In Fig. 8 λ_s and $\Gamma\lambda_a$ are plotted, using these equations and assuming that $Z \simeq A/2$. The value

$$\Gamma \simeq 4$$

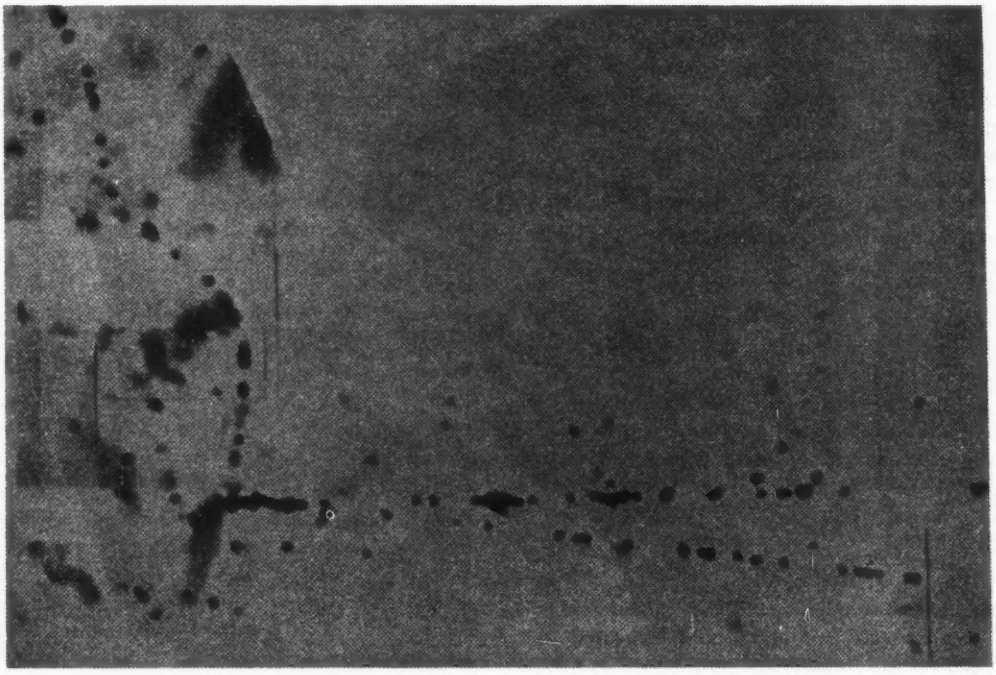

FIG. 6. Backward elastic scattering (meson kinetic energy = 105 Mev, scattering angle = 173°) with a nuclear recoil and slow electron at the vertex. This event was reported by Bernardini *et al.* (reference 24). The two tracks at the right are the incident and elastically scattered mesons.

is consistent with the value which has been estimated[19] from a study of the absorption of stopped π^- mesons in nuclei.[21] However, this determination of Γ is uncertain to within a factor of two. Using this value of Γ and the curves of Fig. 8, one can obtain λ and thus σ_{ab} from Eq. (16) as a

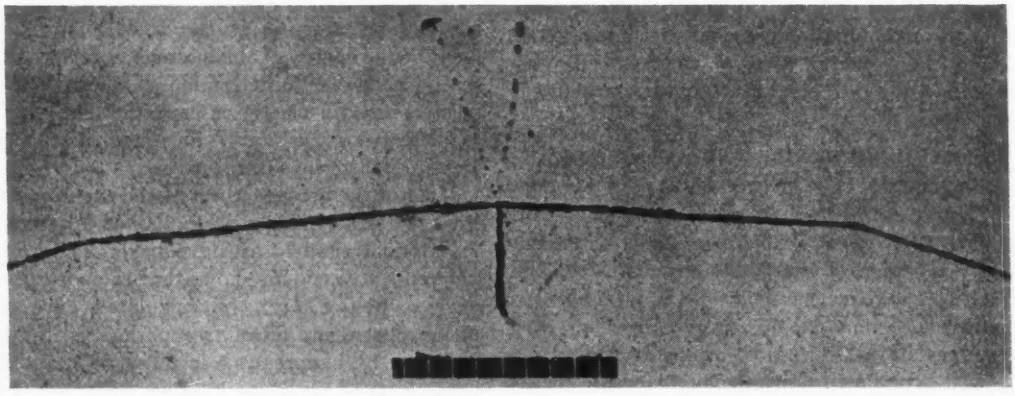

FIG. 7. Inelastic scattering of an 82-Mev π^- on a C_6^{12} nucleus. Each division of the scale is equivalent to 5×10^{-4} cm. The three heavy tracks are α particles, and the light tracks are the incident and inelastically scattered mesons. This event was reported by Bernardini *et al.* (reference 24).

[21] Panofsky, Aamodt, and Hadley, Phys. Rev. 81, 565 (1951). Panofsky, Aamodt, and Phillips, Phys. Rev. 83, 1057 (1951).

function of both the meson energy and the mass number A. In Table II we give a comparison of some calculated and measured values of σ_{ab}. We recall that $\sigma_{ab}=\pi R^2$ when (λ/R) is small. Since λ appears to *decrease* with increasing meson energy, we conclude that for higher energies (above 50 Mev σ_{ab} will be nearly equal to πR^2 for all except the lightest nuclei). This feature makes a precise experimental determination of λ difficult, since the optical model is not expected to have more than a qualitative validity for the lighter nuclei. However, the estimate that $\Gamma\simeq 4$ made above seems to be quite reasonable, since an appreciable increase or decrease in Γ would cause serious disagreement between at least one of the calculated and measured values of σ_{ab} presented in Table II.

TABLE II. Comparison between experimental and theoretical values of meson absorption cross section.

Meson charge	Meson kinetic energy in Mev	Target element	Absorption cross section $\times 10^{26}$ cm^2 Experimental	Theoretical
+	37	lead	210[a]	170
+ and −	48	carbon	22[b]	18
+ and −	62	carbon	18[c]	21
−	85	carbon	34[d]	26

[a] The absorption cross section measured by K. Button, Phys. Rev. **88**, 956 (1952) has been corrected for Coulomb effects.
[b] A. Shapiro, Phys. Rev. **84**, 1063 (1951).
[c] See reference 10.
[d] Chedester, Isaacs, Sachs, and Steinberger, Phys. Rev. **82**, 958 (1951).

As we have seen, the value of σ_{ab} depends only upon the imaginary part of the optical model potential V (or upon λ) in the approximation which led to Eq. (16). Reference to Eq. (20) shows that the elastic or diffraction scattering depends also upon the real part of V (or the real part of the refractive index n), unless the nucleus is so large that Eq. (20′) is valid. Reference to Eq. (21′) and to Fig. 3 shows that the angular distribution of the diffraction scattering is peaked in the forward direction.

Byfield, Kessler, and Lederman[10] have studied in a cloud chamber the diffraction scattering of 62-Mev positive and negative π mesons from carbon. Except for a pronounced Coulomb-nuclear interference effect, the cross sections for both positive and negative mesons appear to be similar. When a correction is made to remove the Coulomb contribution to the scattering, the

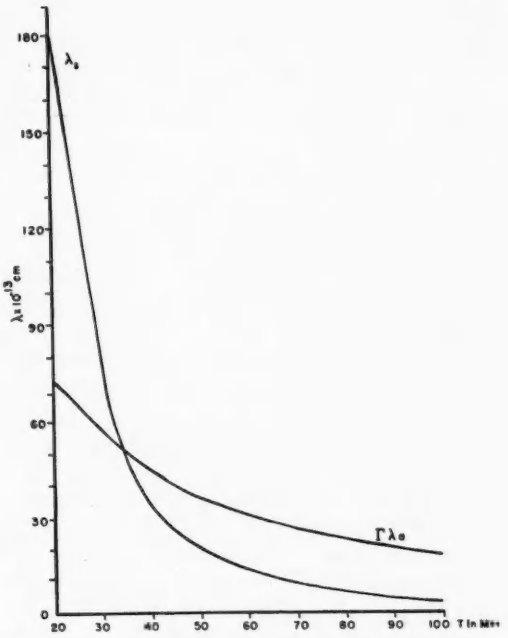

FIG. 8. Calculated values of λ_e and $\Gamma\lambda_e$ plotted against meson kinetic energy.

result is as shown in Fig. 9. From this cross section and the corresponding value of σ_{ab}, Eqs. (16) and (21) can be used to determine the parameters of the optical model. We obtain

$$\lambda=6\times10^{-13}\text{ cm},$$

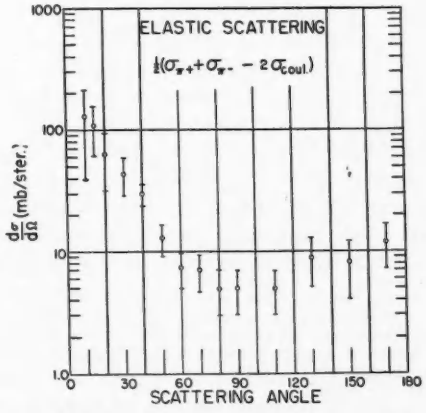

FIG. 9. Differential elastic-scattering cross section for pions on carbon obtained by Byfield *et al.* (reference 10) by averaging the π^+ and π^- results and subtracting the contribution of a uniformly-charged sphere. Note the apparent rise of the cross section for backward scattering angles.

and

$$V=-[23+12i]\text{ Mev.}$$

More careful calculations by Byfield *et al.*, who actually solved the Schrödinger equation (5), lead to

$$\lambda=8\times10^{-13}\text{ cm},$$

and

$$V=-[18+9i]\text{ Mev.}$$

It should be noted from Fig. 9 that the observed diffraction cross section is considerably larger in backward direction than is predicted by the optical model.[22]

In discussing the above experiments we have not considered the true absorption and inelastic scattering separately. We can, however, obtain a qualitative understanding of these two competing reactions from the relative values of λ_s and λ_a, which are given in Fig. 8 (if we assume $\Gamma=4$). For a meson energy of 30 Mev, $\lambda_s=4\lambda_a$, and it is expected that inelastic scattering will be rather infrequent compared to true absorption. However, as the meson energy is increased, λ_s will decrease more rapidly than λ_a, since the former varies as q^{-4} and the latter as v_π/q^2 [according to Eqs. (28) and (29)]. Thus, at higher energies, say 90 Mev, the meson has an appreciable probability of being scattered at least once before being absorbed. Still, λ_a is small at 90 Mev and unless the meson loses a considerable fraction of its energy in the collision to increase its absorption mean free path, it will probably be absorbed before leaving the nucleus.[23] The number of the inelastic meson collisions may therefore be expected to rise sharply as the meson energy is increased from 30 to 90 Mev, and the energy loss of the meson in most of the collisions should be large. Inelastic scattering in the backward direction should be favored for four reasons: (1) The scattering from free nucleons tends to be peaked in the backward direction. (2) The momentum recoil of the struck nucleon is larger for backward scattering, which increases the probability that this nucleon will be ejected from its "orbit" in the nucleus. (3) Mesons which are scattered back out of the nucleus can have traveled a shorter distance in the nucleus, which decreases the probability that they will be absorbed. (4) The backward scattering results in the greatest decrease of the meson energy. At lower energies the absorption mean free path is longer and the mesons are consequently less likely to be absorbed. Bernadini, *et al*,[24] using photographic emulsions to study in detail the true absorption and the inelastic meson scattering cross sections, obtained for π^- mesons the results given in Table III. The expected rapid rise with meson energy of the inelastic scattering cross section is clearly indicated. The almost constant behavior of the true absorption cross section is a consequence of the competition between the inelastic scattering and true absorption effects. At 75 and 105 Mev, σ_{ab} is approximately geometrical in agreement with the previously quoted result of Steinberger. Bernardini also observed that most of the inelastic meson scatterings were at meson scattering angles greater than $\pi/2$ and the average energy loss of the mesons in inelastic collisions was quite large.

Bernardini *et al.* also studied the interaction of π^+ mesons with the nuclei of the photographic emulsion but aside from Coulomb effects and apparent consequences of charge conservation, the π^+ results were the same as those for π^- mesons.

Because of the short lifetime of the π^0 meson, it has been impossible to measure directly the absorption and scattering of π^0 mesons in nuclei. In the next section, where photoproduction of mesons is discussed, we shall see that information about the absorption of π^0 mesons in nuclei can be obtained from a study of the A—dependence of the photoproduction cross sections.

VI. PHOTOMESON PRODUCTION IN COMPLEX NUCLEI

Pi mesons are produced from free protons and neutrons by γ rays of energy greater than 150

[22] D. C. Peaslee, Phys. Rev. **87**, 862 (1952), has interpreted this to be a consequence of the peaking in the backward direction of the cross section for mesons scattered by free nucleons. Such a correction to the optical model can occur for the scattering by light nuclei but is not expected for heavier nuclei.

[23] Because of the Pauli exclusion principle, the recoil nucleon in meson scattering must have a momentum in excess of the Fermi momentum. This effect would reduce slightly the probability for inelastic meson scattering and raise the average energy loss of the meson in an inelastic collision.

[24] Bernardini, Booth, Lederman, and Tinlot, Phys. Rev. **80**, 925 (1950); Bernardini, Booth, and Lederman, Phys. Rev. **83**, 1075 (1951); Bernardini, Booth, and Lederman, Phys. Rev. **83**, 1277 (1951); Bernardini, Booth, Lederman, and Tinlot, Phys. Rev. **82**, 105 (1951). Similar photographic experiments have been performed by Bradner and Rankin, Phys. Rev. **80**, 916 (1950); **87**, 547 (1952).

Mev. The basic reactions are:

$$\gamma+p\rightarrow\pi^{+}+n \quad (\alpha),$$
$$\pi^{0}+p \quad (\beta),$$
$$\gamma+n\rightarrow\pi^{-}+p \quad (\gamma),$$
$$\pi^{0}+n \quad (\delta).$$

For the production of π mesons from atomic nuclei, the simplest assumption which one can make is that the cross section is just the sum of the cross sections from the individual neutrons and protons. In this case we would expect, for instance, the total cross section for the production of positive and negative mesons from a nucleus of mass number A and atomic number Z to be

$$\sigma(A)=A\sigma_f, \tag{31}$$

where

$$\sigma_f=(1/A)[z\sigma(\alpha)+(A-z)\sigma(\gamma)].$$

Here $\sigma(\alpha)$ and $\sigma(\gamma)$ are the cross sections for the above reactions (α) and (γ), respectively. The second equation defines σ_f as the weighted mean of the free nucleon cross sections.

We observed in Sec. II, however, that nuclear binding tends to inhibit free-particle cross sections. We can formally take this into account by inserting a numerical factor η into Eq. (31):

$$\sigma(A)=A\eta\sigma_f. \tag{32}$$

The parameter η then represents the effect of nuclear binding on the photomeson cross sections and is expected to be independent of the mass number A to a fair approximation, since nuclear binding and density do not change very much with A (except for the lightest nuclei). For γ rays of energy between 200 and 300 Mev a reasonable value of η is perhaps

$$\eta\simeq 0.5, \tag{33}$$

an estimate based on a degenerate Fermi-gas model of the nucleus.[25]

We have seen in the last section that mesons are both strongly scattered and absorbed within nuclei. Both of these effects will tend to further decrease the cross section (32). This is obvious in the case of absorption since if an appreciable fraction of mesons are reabsorbed in the same nucleus within which they were produced, then this fraction was effectively not produced at all. The scattering of a meson before leaving the nucleus in which it was produced tends to degrade its energy. If this is by a sufficient amount, the meson is not likely to be detected. Therefore, we must correct Eq. (32) by the fraction f_a of mesons which get out of the nucleus in which they were produced without being absorbed or scattered very inelastically:

$$\sigma(A)=A\sigma_f\eta f_a. \tag{34}$$

The factor f_a has been discussed previously.[19] Rather than to attempt a direct discussion of it, we note that by means of the optical model it can be approximately related to the cross section σ_{ab} (i.e., the cross section for inelastic scattering or absorption in the nucleus A) discussed in the last section (and in Sec. II). The relation is[26]

$$f_a=\lambda\sigma_{ab}/V_A. \tag{35}$$

Here V_A is the volume of the nucleus and λ is the mean free path given by Eq. (30). We have seen in the last section that

$$\sigma_{ab}\simeq\pi a_0^2A^{\frac{1}{3}}.$$

On substituting this expression and

$$V_A=(4\pi/3)a_0^3A$$

into Eq. (35), we obtain

$$f_a=[(3\lambda/4a_0)]A^{-\frac{1}{3}}. \tag{36}$$

Thus, the factor f_a goes to zero with increasing A as $A^{-\frac{1}{3}}$ and Eq. (34) becomes

$$\sigma(A)=[\tfrac{3}{4}(\lambda/a_0)\sigma_f\eta]A^{\frac{1}{3}}. \tag{37}$$

TABLE III. Cross sections in units of 10^{-24} cm^2 for π^- mesons scattered and absorbed by nuclei in photographic emulsions.

Meson kinetic energy in Mev	Stars[a]	Elastic scatterings ($\theta>30°$)	Inelastic scatterings	σ_{ab}
30–50	0.62	0.19	0.06	0.68
60–90	0.76	0.10	0.19	0.95
100–110	0.75	0.16	0.25	1.00

[a] The cross section for stars includes events in which the meson track vanishes. The elastic scatterings must have a scattering angle θ larger than 30°, and the inelastic scatterings are required to have an energy loss in excess of 15 percent of the kinetic energy of the incident meson. The absorption cross section σ_{ab} is the sum of the star and the inelastic scattering cross sections. The experimental results reproduced in this table were obtained by Bernardini and his collaborators (see reference 24).

[25] Such calculations based on this model are described in reference 5.

[26] N. C. Francis and K. M. Watson, Phys. Rev. 89, 328 (1953).

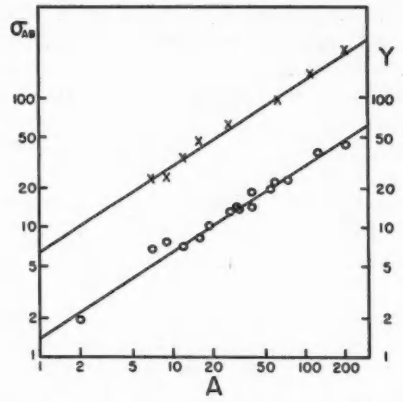

FIG. 10. The circles and X's represent charged meson photoproduction and π^- absorption, respectively. The straight line in each case is the $A^{\frac{2}{3}}$ law. The absorption cross section may be obtained by multiplying σ_{ab} by 10^{-26} cm^2. The experimental points for photoproduction of 65-Mev charged mesons were measured by R. M. Littauer and D. Walker [Phys. Rev. 86, 838 (1952)] and the π^- absorption data measured at 85 Mev is that of Chedester, Isaacs, Sachs, and Steinberger [reference 1d of Table II].

We have indicated that the factor in brackets above is essentially independent of A, so $\sigma(A)$ should vary as $A^{\frac{2}{3}}$, or as the nuclear cross sectional area, rather than linearly with A as implied by Eq. (31). This expectation is exceedingly well verified by experimental measurements of the variation of the photomeson cross sections with the atomic mass number. This is seen in Fig. 10, where Eq. (37) is plotted with the experimental photomeson cross sections of Littauer and Walker. (The experimental cross sections shown are the sum of the cross sections for positive and negative mesons.)

From the measured values of $\sigma(A)$ and σ_f we can obtain from Eq. (27) the product $\lambda\eta$, which turns out be be[27]

$$\lambda\eta = 2.6\times10^{-13} \text{ cm}.$$

[27] Panofsky, Steinberger, and Stellar, Phys. Rev. 86, 180 (1952).

If we take $\eta = 0.5$, then

$$\lambda = 5.2\times10^{-13} \text{ cm},$$

which is in good agreement with the value estimated in the previous section. Panofsky, Steinberger, and Stellar[27] have also studied the photoproduction as a function of A. The behavior again follows the prediction of Eq. (37). The $A^{\frac{2}{3}}$ dependence of the photoproduction of π^0 mesons implies that σ_{ab} for π^0 is also geometrical.

The photomesons which are reabsorbed in the nuclei within which they were produced are expected to lead to energetic nuclear stars. Such photonuclear stars have indeed been observed, and with a cross section which increases rapidly with the γ ray energy above the energetic threshold for meson production. This phenomenon is rather complicated, however, and it seems likely that meson reabsorption may be just one of several mechanisms involved.

VII. SUMMARY

We have seen that the availability of π meson beams has opened for study a new class of nuclear reactions. These are of interest partly for the information which they may give about π mesons and partly for the information which they may give about nuclear structure. The most striking feature of the interactions is their strength, as characterized by geometrical area for many of the scattering cross sections.

An interesting implication concerning nuclear structure results from the estimate that Γ [Eq. (26)] is considerably greater than unity. This quantity was defined as the ratio of the probability in a heavier nucleus to that in deuterium that two nucleons could "find each other" within a small distance d. The largeness of Γ seems to imply that the motion of nucleons in a nucleus is strongly correlated when they are close together. This point has been discussed in more detail in reference 19.

Reproductions of Prints, Drawings, and Paintings of Interest in the History of Physics

56. Four Plates from *A Compleat System of Opticks* by Robert Smith

E. C. Watson
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(Received June 26, 1953)

The first application of the method of constructing the image of a point object by means of an unrefracted central ray and a ray which is parallel to the axis and is refracted through the focus was made by Robert Smith. A section of his *A Compleat System of Opticks* is here reproduced.

THE method of constructing the image of a point object by means of an unrefracted central ray and a ray which is parallel to the axis and is refracted through the focus is taught in almost every elementary course in physics. It was introduced by Robert Smith, Plumian Professor of Astronomy and Experimental Philosophy at Cambridge, in his *A Compleat System of Opticks*, published at Cambridge in 1738. Four plates from this two-volume work, which earned Smith the nickname of "Old Focus" among the Cambridge undergraduates, are here reproduced, together with the accompanying discussion.

The *Compleat System of Optics* is presented in four parts, Book I being "A Popular Treatise," Book II "A Mathematical Treatise," Book III "A Mechanical Treatise," and Book IV "A Philosophical Treatise." Chapter I of Book I treats the reflection and refraction of a single ray at a single surface. Chapter II, after showing how one or more pencils of rays are reflected and refracted by a single surface, continues as follows:

Reflection of a ray through parallel plane surfaces Fig. 43

"A ray of light EF falling obliquely upon a flat piece of glass, or any medium terminated by two parallel planes represented by the lines AB, CD, will emerge from it after both refractions at F and G in a line GH parallel to the incident ray EF. For since any line FG which the ray describes in passing between the parallel planes, is equally inclined to them both, it will be bent as much at G in going forward, as it would be at F in going backward; and these equal bendings being made contrary ways, the incident and emergent rays EF and GH are therefore parallel.

Refraction of a ray through parallel spherical surfaces

"The lines described by the incident and emergent rays EF and GH, being produced are closer together when the glass is thinner, and also when the ray falls less obliquely upon it; because the bendings at F and G are then less: and in these cases if the glass be not flat but bent a little as represented in the 44th figure by two parallel arches AB, CD, the lines EF, GH will still be nearly parallel. For the bended surfaces refract the ray $EFGH$ just as much as two planes would do supposing they touched the surface at F and G: and these planes will be nearly parallel when the line FG is but little inclined to the surfaces; being exactly so when it stands perpendicular to them both.

A lens what Fig. 45 to 50

"A thin piece of glass or of any transparent substance bounded on one side by a polished plane surface, represented by the line EF, and on the other side by a small portion of a polished spherical surface, represented by the arch ACB; or bounded on both sides by spherical surfaces ACB, EDF, is called a lens or simply a glass; and is conceived by mathematicians to be generated or described by turning the figure $ACBFDE$ round

about the line *CD*, drawn through the middle of it perpendicularly to both its sides. This line *CD* produced is therefore called the axis of the lens; and it passes through *G* and *H*, the centers of its surfaces. The points *C*, *D* where it cuts the surfaces are called the vertexes of the lens, and the middle point between them is called its center. The 45th figure represents a plano-convex glass, the 46th a plano-concave, the 47th a double-convex, the 48th a double concave, and the 49th and 50th two concavo-convex glasses, whereof the first is called a meniscus, because it resembles a little moon. It must be remembered once for all, that the thickness *CD* of all these glasses is generally so small, that it seldom need be considered.

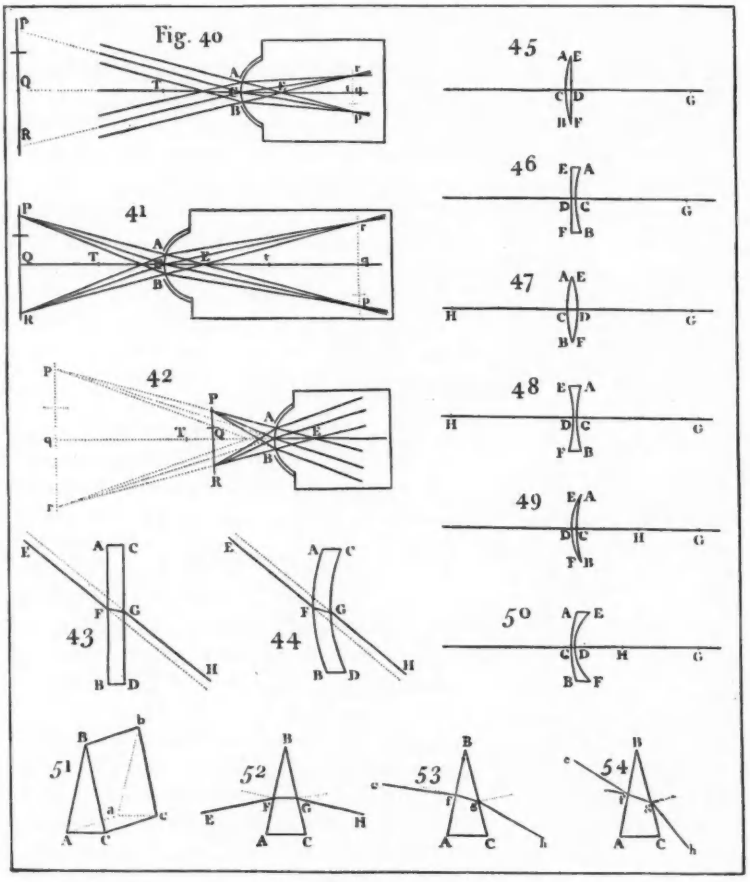

PLATE I.

A prism what Fig. 51

"A glass prism is a body, shaped like a wedge, that has three edges, being bounded with two equal and parallel triangular ends *ABC* and *abc*, and three plane and well polished sides, which meet in three parallel lines *Aa*, *Bb*, *Cc*, running from the three angles of one end to the three angles of the other: and when it is viewed endways it is represented only by a triangle *ABC*, as in the 52d figure.

Refractions of a single ray through a prism
Fig. 52, 53, 54

"When a ray of light *EFGH* is refracted at *F* and *G* in passing through the sides, *AB*, *BC*, of a prism, the course of the emergent ray, *GH*, always deviates from, *EF*, the course of the incident ray, towards the thicker part of the prism, more or less, as the refracting angle *ABC* is greater or smaller. And if the refracting angle be given and the refractions be but small, the quantity of deviation will also be given, though the position of the incident ray be varied at pleasure.

"For supposing at first that the ray *FG*, within the prism, is equally inclined to its sides *AB*, *BC*, as in Fig. 52, it is evident from the positions of the perpendiculars to those sides at the points *F* and *G*, that both the refractions are made from the edge *B* towards the opposite side *AC*.

Fig. 52

"Now let *FG* become unequally inclined to the sides *AB*, *BC*, by turning it gradually into the position *fg*; and while it becomes less and less oblique to one side, suppose *AB*, it will become more and more oblique to the other side *BC*. Consequently supposing a ray to go both ways along this variable line *fg*, it will be more and more bent in going through the side *BC* and less and less in going back through the side *AB*; so that the total bending of the ray, consisting of both its bendings, or angles *efg* and *fgh*, taken together, will continue to be much the same in all its positions. The circulation of the line *fg*, may be further continued till it becomes perpendicular to the side *AB*; and then the bending at this side is nothing: it may also be continued still further till the bending at *f* is made the contrary way; which still takes off from the perpetual increase of the greater bending at *g* and keeps the total bending invariable.

Fig. 53

Fig. 54

"When *fg* is perpendicular to *AB*, let the latter plane *BC* be turned gradually towards the former *BA*, upon the edge *B*, and the ray that comes along *fg* will gradually fall less obliquely upon it; and consequently the bending at *g* will be gradually diminished; and reduced to nothing when the refracting angle *ABC* vanishes. Lastly if several rays be supposed to come parallel to one another they will all emerge parallel to one another. Therefore the quantity of deviation of a ray does not at all depend upon its passage through a thicker or thinner part of the prism, nor upon its inclinations to the sides of the prism, but is proportional to the quantity of the refracting angle *ABC*; and the more exactly as this angle and the refractions at its sides are smaller.

Fig. 53

Refractions of a single ray through the edge of a lens
Fig. 55 to 62

"For the same reason when a ray of light *EFGH* passes through the edge of a convex or concave lens, or the sides of a globe, its emergent part *GH* always deviates from the course of the incident part *EF* towards the thicker part of the glass. Because the refractions at *F* and *G* are the same as if they were made by two planes *FA*, *GC* that touch the spherical surface at *F* and *G*; and so the sides of the glass may be considered as inclined to each other like the sides of a prism.

Refractions of a single ray through the middle of a lens

Fig. 63 to 70

"It follows therefore from the two last articles that the deviation of the course of the emergent ray, from that of the incident ray, is gradually diminished as the ray goes nearer and nearer to the middle of the glass: till, when it goes through the middle, its emergent and incident parts are either parallel to each other, or else are one continued line, when the ray coincides with the axis of the glass. For the angle made by the touching planes, *FA*, *GC*, is gradually diminished as the ray *FG* approaches to the middle: till at last it vanishes when they become parallel.

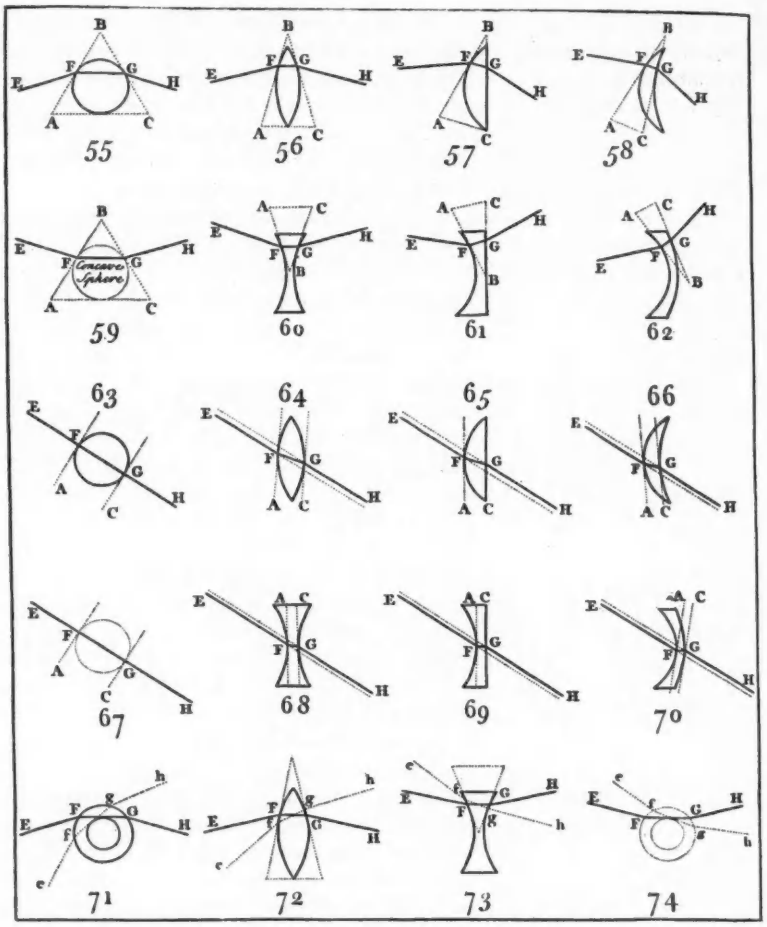

PLATE II.

This ray is considered as straight and is called the axis of a pencil

"When a pencil of rays falls upon any glass, that ray which passes through its center, or middle point, is called the axis of the pencil. And because its incident and emergent parts, *EF* and *GH*, are either one continued line or two parallel lines, its whole course is optical experiments may be always taken for one straight, physical line: from which it differs insensibly when the thickness of the glass is small, and when the pencil falls not too obliquely upon it. Because the parallel lines *EF* and *GH* produced, go closer together in proportion as the line *FG* is shorter, and as the bendings at *F* and *G* are smaller.

Rays are equally bent which pass at equal distances from the center of a globe
Fig. 71, 74

"All rays, as *EFGH* and *efgh*, which cross each other in a refracting globe and pass through it at equal distances from its center, so as to touch a concentrick globe, are equally bent. For in this case the chords *FG*, *fg* being equal, their obliquities to the surface of the globe are also equal, and consequently the bending of the ray *EFGH* at *F* and *G*, both severally and together, are equal to the bendings of the ray *efgh* at *f* and *g*: as is evident

by conceiving the rays to go both ways along the chords *FG*, *fg*. Therefore the angle made by the incident and emergent parts of one ray, produced till they meet, will be equal to the angle made by the incident and emergent parts of the other ray produced till they meet; which is what I mean when I say the rays are equally bent.

And from the center of a lens Fig. 72, 73

"All rays, as *EFGH*, *efgh*, which cross each other at any given point of a lens, or which pass through it at equal distances from its center, are equally bent, provided they do not fall very obliquely upon it. Imagine a line *FG* within the glass, at first to be equally inclined to its sides, and then to be turned a little about any point of it, till it comes into the position *fg*; and while it becomes more and more oblique to one side of the glass, suppose *Ef*, it will become less and less oblique to the other side *Gg*. Consequently if a ray be supposed to go both ways along this variable line *fg* it will be more and more bent in going through the side *Ff* and less and less bent in going through the other side *Gg*: so that the total bending of the ray consisting of both its bendings, or angles *efg*, *fgh*, taken together, will continue to be much the same in all its positions. The circulation of the line *fg*, about the given point, may be farther continued till the bending at *g* is diminished to nothing; and still farther till it be made the contrary way; which still takes off from the perpetual increase of the greater bending at *f* and keeps the total invariable. To keep the same bending it is only necessary that the rays *FG*, *fg* should keep at equal distance from the axis of the lens as near as possible: and nothing alters the total bending but the alteration of that distance; because the inclination of the tangent planes, like the refracting angle of a prism, will then only be altered.

Refraction of a single pencil of parallel rays by any glass Fig. 76, 79, 82, 85, 88, 91

"When a large pencil of parallel rays falls either directly or a little obliquely upon the whole surface of any glass, which is thicker in the middle than at the edges, all the emergent rays will be bent from all sides towards that ray which goes through the middle of the glass: and on the contrary, if the glass be thicker at the edges than at the middle, they will all be bent outwards from the middle ray. And because in both cases the bendings are equal at all distances round about the middle, and grow greater at greater distances from the middle, the emergent rays will all converge pretty nearly to some certain point *F* in the middle ray, if the glass be convex; or diverge from a certain point *F*, if the glass be concave.

Refraction of parallel rays coming contrary ways

"When parallel rays come contrary ways and fall upon opposite sides of any lens, the distance of the focuses of the emergent rays from each side of the center of the lens will be equal; though the semidiameters of the surfaces of the lens be never so unequal, or though one side be plane and the other spherical. For since any two rays which come directly opposite to each other, are at equal distances from the common axis of the pencils, and after crossing each other and emerging from the glass, are equally bent from their first course, these two emergent rays (produced) will meet the axis at equal distances *EF*, *Ef* from the center of the glass. When the rays come parallel to the axis of the lens, their two focuses *F*, *f* are called the principal focuses of the lens: and *EF* or *Ef* is called its focal distance, and by some authors its focal length.

Principal focus and focal distance, what

"On the contrary if the rays be returned directly back from the focus *F* the emergent rays will all be parallel to *FE*, the axis of the pencil.

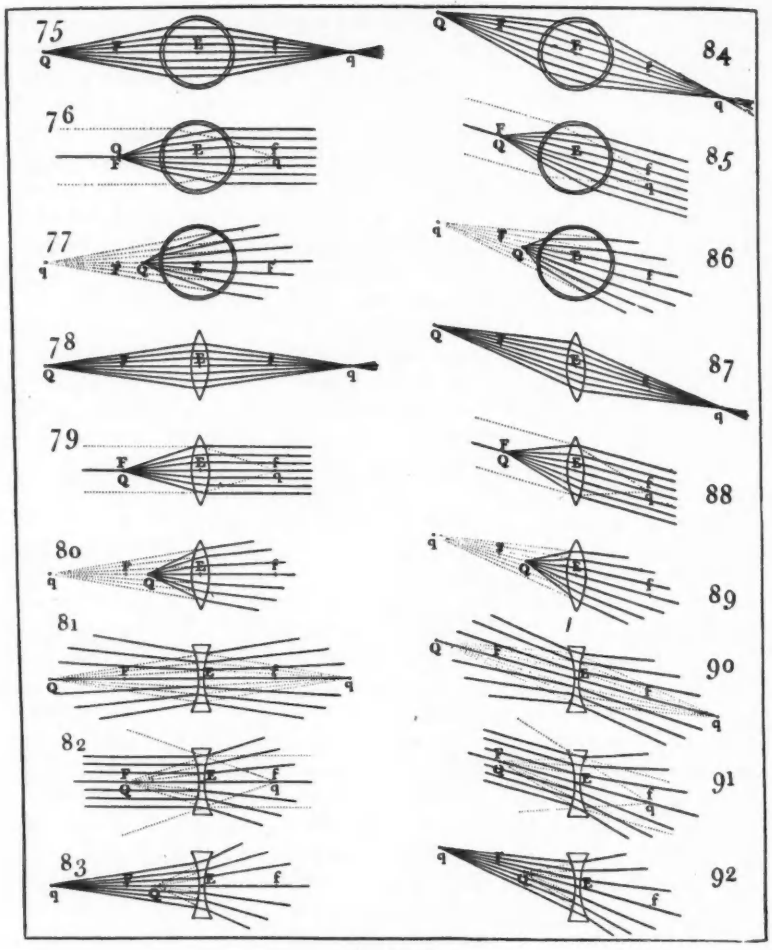

PLATE III.

Refraction of a single pencil of diverging or converging rays through any glass
Fig. 75 to 92

Consequently if this focus F be removed to Q, farther from the glass, the emergent rays will belong to another focus q on the contrary side of the glass; but if Q be put nearer to the glass than F, the emergent rays will belong to a focus q on the same side of the glass as Q. Because while the rays are put into these different situations their bendings will not be altered, if they keep their respective distance from the center of the glass. Consequently if either of the corresponding focuses Q, q be put in motion along the axis of the pencil, either direct or oblique, the other focus will move the say way: and therefore if these focuses be on contrary sides of the glass, while one moves towards it the other will move from it; but if they be both on the same side of the glass, they will both move from it or both towards it; and will come nearer to each other as they come nearer to the glass, till when one coincides with its surface the other will do so too very nearly, provided the glass be very thin and the distance of the ray from the axis be very small. These focuses cannot therefore coincide

at the surface of a globe, because the points of incidence and emergence are too far assunder.

"It is observable that the properties of concave surfaces and glasses are the same as of convex ones; which will appear by conceiving the rays to come contrary ways in the same lines produced; and accordingly to be changed from diverging to converging, and on the contrary: as represented in the figures, by the black lines and pointed lines.

Refractions of several pencils of diverging and converging rays Fig. 93 to 100

"If several focuses *Q*, *R* of incident rays be at any equal distances *EQ*, *ER* from the center of any glass, the focuses of the emergent rays will also be at other equal distances *Eq*, *Er* from the same center in the lines *EQ*, *ER* produced; provided none of the rays fall very obliquely upon the glass. Take any point *A* within the glass, not far from its axis *Qq*, through which a ray passes from the focus *Q* to the focus *q*. Draw the line *AE* and while the figure *QAEq* is conceived to turn a little about the center *E*, into the position *RBEr*, the extremities of the lines *EQ*, *EA*,

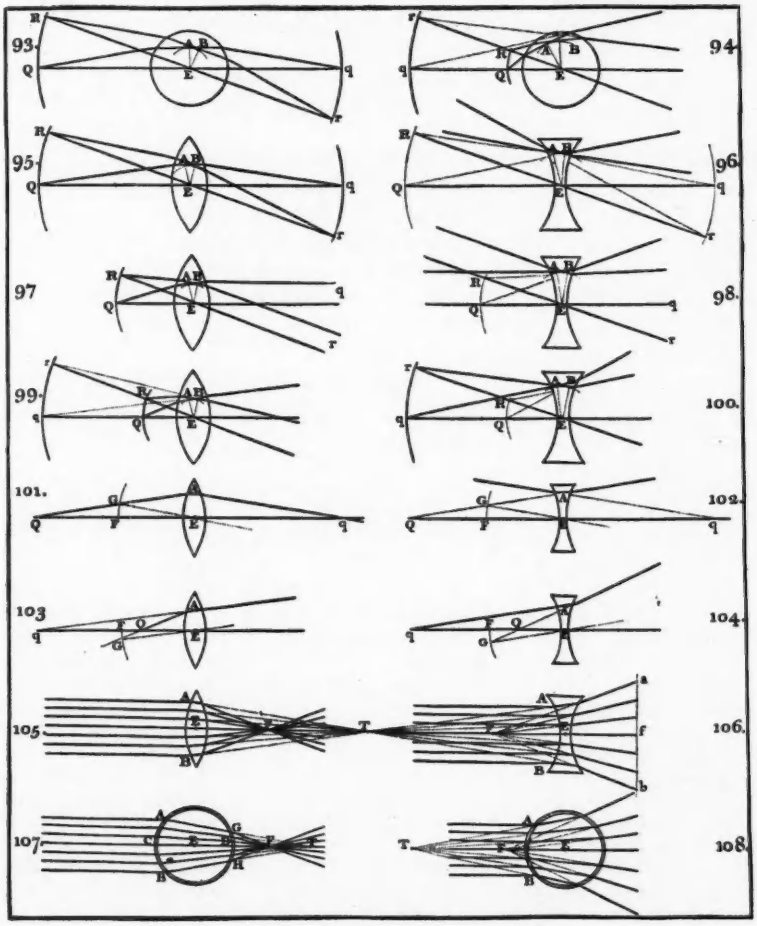

PLATE IV.

Eq will describe small arches *QR*, *AB*, *qr* about that common center *E*. Then let another ray which belongs to the focus *R* be refracted through the point *B*, and after emergence it will belong to the point *r*; because the total bendings of two rays *QAq*, *RBr*, which pass at equal distances, *AE*, *BE*, from the center of the glass, are equal. And the rest of the rays that belong to *R* will belong to the same point *r*; because it is situated in the axis of the pencil.

Refraction of several pencils of parallel rays Fig. 97, 98

"Hence the focuses of all pencils of parallel rays that fall not too obliquely on the same or on opposite sides of any glass are equidistant from its center. For the argument continues the same while the equal distances *Eq*, *Er*, are equally increased till they become infinite, that is till the rays of each pencil become parallel.

Having the focus of incident rays upon a lens to find the focus of the emergent rays Fig. 101 to 104

"Hence if *Q*, the focus of incident rays be given, and *q*, the focus of the emergent rays be required, draw *QE*, the axis of the pencil, and with the center *E* and semidiameter *EF*, equal to the focal distance of the lens, (to be found by experiment) describe an arch *FG* cutting any incident ray, *QA*, in *G*; join *EG* and drawing *Aq* parallel to it, the point *q* where it cuts the axis of the pencil will be the focus of the emergent rays. For supposing other rays, besides *GA*, to flow from or towards *G*, they will all emerge parallel to their axis *GE* produced."

ROBERT SMITH (1689–1768), in addition to being the second Plumian Professor of Astronomy at Cambridge, was Master of Trinity College from 1742–1768, Vice-Chancellor of the University, 1742–3, and the founder of the famous "Smith's prizes" in mathematics. His *A Compleat System of Opticks* was one of the most noted textbooks of the eighteenth century. From it WILLIAM HERSCHEL obtained his first systematic information regarding telescopes and the necessary information to enable him to grind his first mirrors. It is still an important and very helpful reference for the early history of optics.

Practical Aids for Physics Teachers

The *American Journal of Physics* has introduced a new feature under the title, "Practical Aids for Physics Teachers." It has already begun in a small way, but we hope that it will grow to occupy several pages in every monthly issue.

The aids that go under such a title must be contributed; they cannot be prepared in the Editor's office. Material of the following kind would be most welcome:

A. Examination papers that seem to have been successful ones at all levels of difficulty, even into the beginning graduate level, but especially at the elementary level.

B. Problems, particularly at the elementary level; also at the upper undergraduate level. If problems are very difficult, solutions should be provided. They will be printed with the problems.

C. Useful analogies that may be used to clarify some of the basic concepts of physics; or useful illustrations of fundamental ideas.

D. Neat ideas for lecture demonstrations.

E. Useful material in books, magazines or trade journals that are not likely to come to the attention of the average teacher of physics but which offer illuminating discussions of simple matters. Give the reference completely and specifically: summarize in one or two sentences.

The contributor of each item will be recognized in the following way: At the end of each item (or it may be at the beginning) will be placed the following statement: *Contributed by John Doe, Penpoint College.* This form will be used if the contributor wishes to be identified.

Should the contributor not wish to be identified, a form such as the following should be employed, for example, in the case of a contributed examination paper: *Used in a first-year physics course for liberal arts students in a private college of approximately 800 total enrollment.* Or else it might run: *Used in a physics course for sophomore engineering students in a state university of total enrollment 15 000.*

Now you see what I mean. Please send me contributions. The only stipulation that I must make is that everything must be typed double-spaced. When I say everything, I mean *everything*. Otherwise, there is no room for editorial markings. A mimeographed copy that is already double-spaced and of good quality would be acceptable.

This is your Journal, your Association. Won't you help?

THOMAS H. OSGOOD
Editor

The cgs Units of Magnetic Susceptibility and Specific Magnetization*

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(Received January 28, 1953)

The units of susceptibility and magnetization can be chosen so that they are identical in the (unrationalized) 3- and 4-dimensional cgs systems. These units and the defining equations are given, and inconsistencies in the literature are pointed out. Adoption of the present definitions would eliminate much existing confusion and satisfy the various schools of thought.

THE magnetic properties of substances may be used in elucidating their molecular structure, determining their chemical composition and purity, and studying their chemical reactions.[1] The quantities most useful for these purposes are susceptibility (for diamagnetic and paramagnetic materials) and magnetization (for ferromagnetic materials). The susceptibility (volume, specific, atomic, or molar) of a diamagnetic or paramagnetic substance is generally independent of the intensity of the applied magnetic field. However, this property is a complicated function of the field in the case of ferromagnetic substances, becoming virtually independent of it only at sufficiently high field strengths. Intensity of magnetization at saturation, or saturation specific magnetization, is therefore used to characterize ferromagnetic substances. Both types of magnetic constants are measured by determining the force exerted on a substance by an inhomogeneous magnetic field. Although an extensive literature exists on the numerical values of the magnetic constants of a wide variety of materials, the units of these constants are rarely given, possibly because of the confusion that still exists with respect to the dimension of magnetic permeability.

The purpose of this note it to derive the units of susceptibility and magnetization in such a manner that they are equally applicable to the 3- and 4-dimensional cgs systems and to show that the equations relating mechanical and magnetic forces differ slightly for these two systems when the present definitions are used. Since the numerical values of the magnetic constants are traditionally given in the unrationalized cgs system, only that system will be considered.

3-DIMENSIONAL SYSTEM

Even today, the most widely used form of the basic magnetic equation relating magnetic induction or flux density B, field intensity or magnetizing force H, and intensity of magnetization I is

$$B=H+4\pi I, \tag{1}$$

even though this form does not correspond to present international convention. However, it is based on a self-consistent system of units.[2,3] In this system, the units of B, H, and I are (erg $cm^{-3})^{\frac{1}{2}}$, that is, $[B]=[H]=[I]$. On dividing Eq. (1) by H, one obtains

$$\mu=B/H=1+4\pi\kappa, \tag{2}$$

μ being the dimensionless magnetic permeability and κ the dimensionless volume magnetic susceptibility. The specific magnetic susceptibility (susceptibility per gram of substance) is

$$\chi=\kappa/d, \tag{3}$$

where d is the density of the substance. Thus, χ has the units of reciprocal density. (The symbol for specific magnetic susceptibility is sometimes written as χ_g). The atomic or molar magnetic susceptibility is

$$\chi_A=A\chi \quad \text{or} \quad \chi_M=M\chi, \tag{4}$$

where A and M are gram-atomic and gram-molecular weight, respectively. Specific magnetization,

$$\sigma=I/d=\chi H, \tag{5}$$

* Published by permission of the Director, Bureau of Mines.

[1] P. W. Selwood, *Magnetochemistry* (Interscience Publishers, Inc., New York, 1943), p. 8

[2] P. W. Bridgman, *Dimensional Analysis* (Yale University Press, New Haven, Connecticut, 1946), p. 111.

[3] W. Klemm, *Magnetochemie* (Akademische Verlagsgesellschaft m.b.H., Leipzig, 1936), p. 18.

has the units of H (or B) multiplied by reciprocal density, gauss cm^3g^{-1}, and, multiplying by (gauss/gauss), this is equivalent to erg $gauss^{-1}$ g^{-1}. Only the latter expression is common to both systems.

4-DIMENSIONAL SYSTEMS

According to present international convention,[4] μ is considered to be a dimension, and H and B do not have the same dimensions (see Table I). Equation (1) has been erroneously used in this 4-dimensional system. Unfortunately, no generally accepted convention exists regarding the dimensions of I in this system. Thus, one finds

TABLE I. Some units and equations in the cgs electromagnetic system.

Symbol	Units $[B]=[H]=[I]$	$[H]=[I]$	$[B]=[I]$
I	$(\text{erg cm}^{-3})^{\frac{1}{2}}$	$\mu^{-\frac{1}{2}}(\text{erg cm}^{-3})^{\frac{1}{2}}$	$\mu^{\frac{1}{2}}(\text{erg cm}^{-3})^{\frac{1}{2}}$
H	$(\text{erg cm}^{-3})^{\frac{1}{2}}$	$\mu^{-\frac{1}{2}}(\text{erg cm}^{-3})^{\frac{1}{2}}$	
B	$(\text{erg cm}^{-3})^{\frac{1}{2}}$	$\mu^{\frac{1}{2}}(\text{erg cm}^{-3})^{\frac{1}{2}}$	
μ	none	μ	
κ		none	
χ or χ_g		$g^{-1}cm^3$	
χ_A		g-atom^{-1}cm^3	
χ_M		g-mole^{-1}cm^3	
σ		erg $gauss^{-2}g^{-1}$	

Equations

$B=H+4\pi I$	$B=\mu_0(H+4\pi I)$	$B=\mu_0 H+4\pi I$
$\mu=B/H=1+4\pi\kappa$	$\mu=B/H=\mu_0(1+4\pi\kappa)$	
	$\chi=\kappa/d$	
$\sigma=\chi H=I/d$		$\sigma=\chi H=I/\mu_0 d$
$F=\chi mH(dH/dx)$	$F=\mu_0\chi mH(dH/dx)$	
$F=\sigma m(dH/dx)$	$F=\mu_0\sigma m(dH/dx)$	

the dimensions of H[5] or of B[6,7] assigned to I by different authors.[8] There are therefore two ways of rewriting Eq. (1). However, when the defining equations of Table I are used, the units and numerical values of χ and σ are identical in the 3- and 4- dimensional systems, and κ is dimensionless in all cases.[5] The units of σ are now oersted cm^3g^{-1}, but multiplication by (gauss/gauss) again yields erg $gauss^{-1}g^{-1}$. The equations relating mechanical force F (dynes) to magnetic force are given in Table I. With the present definitions for χ and σ, the factor μ_0 (permeability of free space) must be inserted in the force equations for the 4-dimensional systems for the sake of homogeneity.

In only four cases have the writers found the units for susceptibility expressed: In one instance,[9] χ_M was given as erg $oersted^{-2}$ $mole^{-1}$. This is correct only for the 3-dimensional system; in the 4-dimensional system (in which the term "oersted" was first introduced), this becomes erg $gauss^{-1}$ $oersted^{-1}$ $mole^{-1}$, but cm^3 $mole^{-1}$ is more convenient and equally applicable to all systems. In another case,[10] cm^3 was given erroneously for both χ and χ_M. Merkel used a wrong defining equation for σ.[11] Cuevas gave the units of χ and χ_M correctly.[12] It may be mentioned that the *International Critical Tables* are not consistent in their usage: Equations (1) and (2) of this paper are mentioned (Vol. 6, p. 369), even though the relationship $B=\mu_0 H+4\pi I$ should have been used. Susceptibility (volume susceptibility is meant) unfortunately is given the dimension μ (Vol. 1, p. 31).[13] Recent editions of the *Handbook of Chemistry and Physics* have followed ICT usage. However, the definitions given here appear to be the only ones compatible with both the old and new systems, thus avoiding much confusion.

[4] A. E. Kenelly, J. Inst. Elec. Engrs. (London) **78**, 235 (1936).
[5] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill Book Company, Inc., New York, 1941), pp. 11–13.
[6] G. P. Harnwell, *Principles of Electricity and Electromagnetism* (McGraw-Hill Book Company, Inc., New York, 1938), pp. 349, 357.
[7] E. W. Washburn, ed., *International Critical Tables* (McGraw-Hill Book Company, Inc., New York, 1926), Vol. 1, p. 31.
[8] R. L. Sanford (private communication) has pointed out that $[I]=[B]$ is incorrect in the 4-dimensional system.
[9] Friedman, Hunt, Plane, and Taube, J. Am. Chem. Soc. **73**, 4028 (1951).
[10] K. Gleu and I. Büdecker, Z. anorg. u. allgem. Chem. **268**, 202 (1952).
[11] H. Merkel, Chem.-Ing.-Tech. **23**, 570 (1951).
[12] J. D. C. Cuevas, Ph.D. thesis, University of Michigan (August 1948), University Microfilms Publication No. 1097.
[13] V. P. Hessler (private communication) has derived several variants of the 4-dimensional system including the one used in the *ICT*. It has the disadvantage of not yielding parallel definitions for χ and σ in the 3- and 4-dimensional systems.

Radiation Pressure Against Perfect Reflectors

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(Received April 6, 1953)

The concept of radiation pressure exerted against a reflecting surface by electromagnetic waves and by sound waves in gases is a familiar one. The absence of radiation pressure for sound waves in a "linear medium" is becoming well known. The equations are somewhat different for the radiation pressure for these two cases where the radiation pressure is not zero. The mechanisms usually called on to explain them (nonlinearity of the equation of state of the gas, acceleration of charges in the reflector by the electromagnetic waves) are widely removed from each other. Consequently, it is not evident on the surface whether radiation pressure is a general property of waves or the capricious result of isolated physical phenomena associated with some waves.

A generalized concept of radiation pressure is here developed and then applied to several kinds of waves: sound waves in various media, waves on strings and springs, electromagnetic waves. Also, a simple demonstration of radiation pressure (for waves in a ripple tray) is described.

IT is well known that the radiation pressure of electromagnetic waves incident perpendicularly on a surface is equal to the energy density directly in front of the surface. The pressure exerted by a sound wave incident on a surface is sometimes equal to the energy density and sometimes only proportional to the energy density, and sometimes this factor of proportionality is zero. The details of sound-wave radiation pressure have been discussed[1,2] in recent papers. Both of these dealt with equations of the sound field and averaged the pressure at the reflecting or absorbing surface. These papers showed considerable physical insight into why the pressure to be observed takes on one value or another. The following has been assembled to point out some heuristic approaches to the problem, not only for sound waves, but also for other mechanical waves and also to present some general features of wave pressure or radiation pressure for all kinds of waves incident on a highly reflecting surface.

A universal test for the amount of radiation pressure to be observed at a surface under any experimental conditions is to ascertain the work required for a slow adiabatic virtual displacement of the reflecting surface *under the existing experimental conditions;* the work per unit area per unit of displacement *due to the wave field* is the radiation pressure of the field.

For normal incidence of sine waves on a highly reflecting surface, the surface faces a standing wave field. Any work done by the surface in a virtual displacement results in adding energy to this field. There is no objection, then, to the device of assuming the standing wave field to be bounded by another reflector, possibly far away, parallel to the first so that the standing wave field can be simulated by a normal mode for the medium between. One has then to calculate the energy added to this normal mode by a virtual displacement.

A concept from quantum mechanics fits into this picture very cleanly. The normal mode is equivalent to an oscillator. Any adiabatic process may shift the energy levels of the states of the oscillator, but each state retains its identity, and the adiabatic process will not cause transitions from one state to another. In any particular state the energy of an oscillator is proportional to the oscillator frequency, so an adiabatic process that shifts the frequency of an oscillator from ν to $\nu+d\nu$ shifts its energy from E to $E+dE$, with

$$dE/E=d\nu/\nu. \tag{1}$$

This result can be obtained for a reversible adiabatic change of the parameters of a classical oscillator too, but the result is more familiar for the quantum-mechanical oscillator.

The virtual work done during a virtual displacement of one of the end reflectors is just the energy of the mode considered multiplied by the fractional change of frequency.

[1] R. T. Beyer, Am. J. Phys. **18**, 25 (1950).
[2] A. Schoch, Z. Naturforsch. **7a**, 273 (1952).

For a normal mode consisting of n half-waves between the surfaces, the separation of the surfaces is $l=n\lambda/2=nc/2\nu$, where c is the phase velocity of the waves and λ is the wavelength. A virtual displacement of one of the reflecting surfaces dl results in a frequency change

$$d\nu=-(nc/2l^2)dl+(n/2l)(\partial c/\partial l)dl.$$

The virtual work is $dE=(E/\nu)d\nu=-Ap\,dl$, where A is the area of the reflector, and p is the radiation pressure. Since the energy density in the wave field is $u=E/Al$,

$$p=-(1/A)(dE/dl)=-(E/A\nu)(d\nu/dl)$$
$$=-(ul/\nu)(d\nu/dl)=(un/2\nu)(c/l-\partial c/\partial l).$$

Hence

$$p=u\left(1-\frac{l}{c}\frac{\partial c}{\partial l}\right). \qquad (2)$$

In the factor of proportionality relating p to u, the partial derivative, $\partial c/\partial l$, is taken under the conditions demanded by the physical situation.

Equation (2) indicates that for any situation where phase velocity c is not altered by moving the reflector, the radiation pressure is just equal to the energy density. This is the situation with electromagnetic waves in vacuum. It is the situation with acoustic waves when the fluid carrying the waves can flow freely into or out of the sound field. In physical situations where $p\neq u$, the virtual displacement must bring about some change in the medium that results in a change in c.

SOUND WAVES

For fluid confined to a rigid walled tube, so that the fluid will be compressed by a virtual displacement, one will generally not find that $\partial c/\partial l$ is zero.

An ideal gas with constant ratio of specific heats γ has $c=(\gamma RT/M)^{\frac{1}{2}}$, where R is the universal gas constant, M the molecular weight, and T the absolute temperature. An adiabatic virtual displacement of a rigid reflecting piston in a rigid walled tube of uniform cross section requires that $Tl^{\gamma-1}$ be constant during the displacement. Hence $\partial T/\partial l=(1-\gamma)T/l$, and $\partial c/\partial l=(c/2T)(\partial T/\partial l)=(1-\gamma)c/2l$. Equation (2) then gives for radiation pressure,

$$p=\tfrac{1}{2}(\gamma+1)u.$$

This is the "Rayleigh radiation pressure" as obtained by Rayleigh,[3] and confirmed by Beyer[1] and Schoch.[2]

The Rayleigh radiation pressure can be calculated by Eq. (2) for any fluid whose pressure in an adiabatic compression is available as a function of its density. When three terms of a series expansion in $\Delta\rho$, the deviation of density from its initial value, are sufficient, such a function takes the form

$$P=P_0+P'\Delta\rho+\tfrac{1}{2}P''(\Delta\rho)^2$$
$$=P_0+c^2\Delta\rho+c(\partial c/\partial\rho)(\Delta\rho)^2. \qquad (3)$$

In a closed tube of length l, $d\rho/dl=-\rho/l$. Then $\partial c/\partial l=(\partial c/\partial\rho)(d\rho/dl)=-\rho P''/2cl$. The radiation pressure on the tube end or on a piston in the tube is, by Eq. (2),

$$p=u(1+\rho P''/2c^2), \qquad (4)$$

also the result of Rayleigh[3] and pointed out by Beyer.[1]

A fluid that obeys Hooke's law shows zero Rayleigh radiation pressure. The condition that fluid pressure be proportional to the difference in volume from equilibrium volume requires that $\partial c/\partial l=c/l$. Details of these considerations are completely analogous to those for longitudinal waves on a spring presented below.

A beam of sound waves in a nonclosed medium shows a radiation pressure, $p=u$. The virtual displacement against the sound field does not change the medium but expels some of the medium out of the beam, so $\partial c/\partial l=0$.

A linear fluid, one that obeys Hooke's law and shows no Rayleigh radiation pressure has, for a beam through the open medium, fluid flowing into the region of the sound field as the sound field intensity is increased so that the average density is higher in the sound field than in the surrounding medium. The higher density requires a higher average pressure than existed before the sound field was established. This increase in average pressure because of the presence of the sound field is the radiation pressure.

A heuristic explanation of the mechanism of the radiation pressure of a fluid obeying Hooke's law is that the instantaneous pressure at the surface of the reflector oscillates symmetrically about the mean pressure in the sound beam.

[3] Rayleigh, Phil. Mag. 3, 338 (1902); 10, 364 (1905).

In the case of a closed medium this mean pressure is, not surprisingly, the fluid pressure that would exist if the sound field were removed. In the open fluid this mean pressure is greater than the pressure would be without the sound field. At the instant that the pressure at the reflector passes this mean, all of the energy in the standing-wave pattern is kinetic. Viewed from the side of the beam, the motion of the fluid makes the beam present a pressure less than the pressure on the reflector by the amount given by Bernoulli's equation $\frac{1}{2}\rho\langle v^2\rangle_{Av}$, where $\langle v^2\rangle_{Av}$ is the space average square of the particle velocity at that time. For equilibrium, sufficient fluid must have passed into the beam from the surroundings to raise the mean pressure by just this amount. But at the instant in question $\frac{1}{2}\rho\langle v^2\rangle_{Av}$ is just the energy density in the beam. This derivation is admittedly heuristic; deeper insight into the details of the passage of fluid into the beam can be obtained from Beyer's paper[1] or from the references he cites.

For a medium that obeys some other law than Hooke's law, fluid will flow into or out of the sound beam as required to render $p=u$.

The energy density of the waves u is the energy density of the waves in the medium as it exists, and does not include the energy associated with the work done by the surrounding fluid when fluid moves into the beam.

TRANSVERSE WAVES ON A STRING

Waves on a string have $c=(T/\rho')^{\frac{1}{2}}$, where ρ' is the linear density of the string and T the tension. The force F on the terminals of the string due to the presence of the waves corresponds to pressure on the reflector for sound waves.

There are two cases, corresponding to sound waves in the unconfined fluid and in the confined fluid. Corresponding to the unconfined fluid is a string terminated by a fret or close-fitting ring to restrict its transverse motion. Corresponding to the hydrostatic pressure on the fluid is a device to keep the tension on the string beyond the ring fixed at T (Fig. 1).

The instantaneous horizontal force on the ring is $\alpha^2T/2$, where α is the angle the string, at the ring, makes with its equilibrium position. The time-average horizontal force is $F=\langle\alpha^2\rangle_{Av}T/2$, where $\langle\alpha^2\rangle_{Av}$ is the mean-square value of α. The time-average vertical force on the ring is zero.

The energy density u' of a standing wave on the string is just $\langle\alpha^2\rangle_{Av}T/2$, so $F=u'$, corresponding to $p=u$ for radiation pressure of sound waves on a reflector in an unconfined fluid. This result is in accord with Eq. (2) since in this physical situation the wave velocity c is independent of displacements of the ring along the string. Corresponding to fluid flowing into the sound beam when the fluid is unconfined is the string moving through the ring into the region where the wave is, lifting the weight that maintains tension on the rest of the string. The string will move in until the average tension on the wave side of the ring is just T. Then the average horizontal component of T will be less by some amount, and

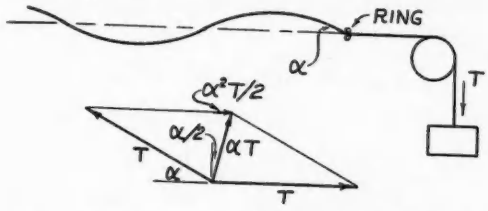

FIG. 1. Diagram of a vibrating string constrained at one end by a fret or ring that limits its transverse motion, but not its motion through the ring at a slow rate. The force diagram shows the instantaneous force on the restraining ring. The vertical component of the force averages zero in time, while the horizontal component averages $T\langle\alpha^2\rangle_{Av}/2$ away from the wave motion.

the string will adjust the horizontal positions of its particles until the time-average horizontal component of T is the same everywhere along the wave. This readjustment is here considered subject to the approximation that the wave motion is entirely transverse.

For a string with the ends fixed to rigid supports the force on the support is T without the presence of the wave, but is reduced by $[\langle\alpha^2\rangle_{Av}T/4-(\langle\alpha^2\rangle_{Av}l/4)(\partial T/\partial l)]$ when a wave is present. This reduction of tension on the support is the radiation force F.

There is an instantaneous net lengthening of the string of $\alpha^2l/4$ (to a first order approximation) when there are sinusoidal standing waves on the string. Here l is the length of the string. This stretching increases the time-average force on the end support by $(\langle\alpha^2\rangle_{Av}l/4)(\partial T/\partial l)$, $\partial T/\partial l$ is the increase in tension per unit length of string,

and depends upon the elastic properties of the string.

To keep the average horizontal component of tension constant along the string, the tension at loops of the waves must be less than that at the nodes by the fraction $\langle 1-\cos\alpha\rangle_{Av}\cong\langle\alpha^2\rangle_{Av}/2$. With no readjustment of horizontal particle positions in the presence of the waves the total tension at the nodes, and therefore the ends, would be $T(1+\langle\alpha^2\rangle_{Av}/2)$ when the tension at the loops was T. Readjustment does take place, however, decreasing the tension at the loops by the fraction $\langle\alpha^2\rangle_{Av}/4$ and decreasing the mean tension at the ends by the same fraction. The horizontal component of tension at the ends is just the same as the horizontal tension (which is the total tension) at the loops and has a mean value less by the fraction $\langle\alpha^2\rangle/4$ than the tension with no waves.

The final result,

$$F=(\langle\alpha^2\rangle_{Av}T/4)[1-(l/T)(\partial T/\partial l)],$$

is what Eq. (2) yields, since $u'=\langle\alpha^2\rangle_{Av}T/2$, and

$$\frac{l}{c}\frac{\partial c}{\partial l}=\frac{l}{2}\left(\frac{1}{T}\frac{\partial T}{\partial l}-\frac{1}{\rho'}\frac{\partial\rho'}{\partial l}\right)=\frac{1}{2}\left(\frac{l}{T}\frac{\partial T}{\partial l}+1\right).$$

LONGITUDINAL WAVES ON A SPRING

A coil spring that obeys Hooke's law, with spring constant k, length l, and linear density ρ'', will propagate a longitudinal wave at velocity $c=(kl/\rho'')^{\frac{1}{2}}$. Waves on such a spring clamped at both ends exert no radiation force.

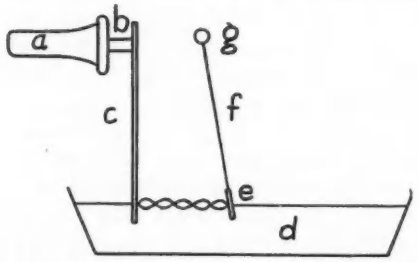

FIG. 2. Apparatus for demonstrating wave pressure. Telephone receiver a is connected to an oscillator, and has its diaphragm in contact with b, which is some part of the clamp that supports a stiff sheet metal plate c, which in turn excites ripples in the pan of water d. Aluminum, 1/16 inch thick, has been used for c. A thin Micarta strip e is suspended in the water parallel to c by threads f which are fastened to a support bar g. When strong standing ripples are excited between the ripple source c and reflector e, a deflection of e from its equilibrium position is easily observed.

Equation (2) gives

$$F=u\left[1-\frac{lk}{2c^2}\frac{\partial}{\partial l}\left(\frac{l}{\rho''}\right)\right]=u(1-lk/\rho''c^2)=0.$$

This is analogous to the sound wave in the confined linear fluid that also obeyed Hooke's law.

For such a spring the frequency of any mode is independent of the length to which the spring is stretched. This can be checked experimentally by exciting a steel coil spring through its (almost rigid) support with a telephone earpiece driven by a laboratory oscillator. The resonant frequency is independent of the elongation. Likewise, the zero radiation force can be demonstrated by stretching the spring vertically between a bracket and a weight and placing a dial indicator in contact with the weight. When a standing wave is established by the oscillator and earpiece acting through the supporting bracket above the spring, no perceptible motion of the weight is to be seen.

In one such demonstration with a dial indicator having a sensitivity of one dial division per 0.0001 inch, movement of the weight upon establishing a standing wave was less than 0.00003 inch, while calculations based on observed wave amplitude and the properties of the spring showed that movements of the order of 0.001 inch were to be expected if the radiation force were equal to the linear energy density of the wave.

A SIMPLE DEMONSTRATION OF RADIATION PRESSURE

Radiation pressure of electromagnetic waves and sound waves has been detected and measured, but the experiments involved very delicate instruments for observing the very small forces, or in the case of some ultrasonic waves, very intense fields. A demonstration of radiation pressure that can be quickly arranged and that requires no special equipment should be made with waves whose energy density is commonly much higher than electromagnetic or acoustic wave fields. Also, of course, the coefficient of u in Eq. (2) must not be zero, as was the case with the waves on the spring of the last section. At least two classes of waves satisfy the criteria,

surface ripples on a liquid, preferably water with its high surface tension, and gravity waves on liquid.

Apparatus shown in Fig. 2 is very easily set up, and when the oscillator frequency is tuned to excite standing ripples between the suspended reflector and the radiating plate the Micarta reflector moves away from its equilibrium position, sometimes half an inch or more. A low audio-frequency is satisfactory. A similar demonstration at still lower frequencies would involve gravity waves instead of surface ripples.

A set of needles, each mounted on a screw threaded through a bar, and suitable electrical circuits for ascertaining when the needle made contact with the water, could measure the height of the ripples and hence render the demonstration quantitative.

ELECTROMAGNETIC WAVES

In vacuum, the phase velocity of electromagnetic waves c_0 is constant, and in any physical situation involving a virtual displacement of a reflector, the phase velocity is independent of the displacement. The radiation pressure, by Eq. (2), is just the energy density u. This familiar result has been obtained from several different approaches.

In one statistical-mechanical treatment of blackbody radiation a mode of oscillation in a cavity is treated as a quantum-mechanical oscillator. The thermodynamic functions of the oscillator are calculated on the basis of the energy-level scheme, and the pressure exerted on the cavity by the mode in question is $-(\partial A/\partial V)_T$, where A is the work function of the mode. The thermodynamic functions are calculated with the condition that the velocity of light is independent of cavity volume. For a mode like those here considered, where the wave propagation is perpendicular to the cavity walls, the result is that radiation pressure is equal to u. This treatment is equivalent in every way to that carried out above which resulted in Eq. (2), except that c is assumed constant early in the development. The rest of the development in the case of blackbody radiation consists of suitably summing the effects of all modes in the cavity to get the thermodynamic functions of the total black radiation.

The statistical-mechanical treatment of blackbody radiation as a photon gas is more closely analogous to the classical kinetic theory of gases than to classical wave motion.

Electromagnetic theory offers a model for the mechanism of radiation pressure. The electric field is envisioned as accelerating charges in the reflecting medium along the surface, and these charges are turned into the surface by the accompanying magnetic field where they exchange their acquired momentum. Detailed calculation yields the result that for perpendicular incidence the pressure is equal to the energy density of the field in front of the surface[4] whether the surface is absorbing or reflecting.

The perfect reflector is a limiting case where the electric field at the surface approaches zero but the acceleration of charges in the surface does not, and the magnetic field becomes twice the value of the magnetic field of the incident wave. The magnetic forces on the currents in the surface still give a pressure equal to the energy density in the field.

This pressure is independent of properties of the medium where the field is, so some explanation is necessary for the difference indicated by Eq. (2) for an electromagnetic wave through a gas in a closed and in an open cavity. If the electromagnetic waves are propagated through a gas whose dielectric constant is given as a function of gas density ρ, by $k=1+\sigma\rho$, then the phase velocity c is $c=c_0/k^{\frac{1}{2}}\cong c_0(1-\frac{1}{2}\sigma\rho)$. Equation (2) gives $p=u$ if the gas is unconfined, and when the gas is confined, $p=u(1-\frac{1}{2}\sigma\rho)$. In both cases there is an electrostriction on the gas due to the mean electric field that reduces the hydrostatic pressure of the gas[5] by $\frac{1}{2}\sigma\rho u$, but with the unconfined gas, there is gas flow into the field that is just sufficient to restore the pressure to that in the free gas.

[4] G. P. Harnwell, *Principles of Electricity and Electromagnetism* (McGraw-Hill Book Company, Inc., New York, 1938), pp. 537–538.

[5] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill Book Company, Inc., New York, 1941), pp. 149–151. If one applies these equations for electrostriction, one must keep in mind that u is twice the mean electrostatic energy in the electromagnetic field.

NOTES AND DISCUSSION

The Bohr Formula for Nonrelativistic Elliptic Orbits

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FOR circular orbits, the relation between energy and principal quantum number in the Bohr model of the atom is easily derived from elementary principles. In contrast, the derivation of the same relation for the general case of degenerate elliptic orbits is customarily presented in a much more formidable form. The procedure followed, as far as the author is aware, is to evaluate explicitly the radial phase integral

$$J_r=\oint p_r dr=\oint\left[2m\left(E-\frac{(J_\theta+J_\phi)^2}{4\pi^2r^2}+\frac{Ze^2}{r}\right)\right]^{\frac{1}{2}}dr$$

in terms of the energy E and the remaining phase integrals J_θ and J_ϕ. Whether elementary substitutions are used,[1] or the more elegant Sommerfeld method of integration in the complex plane is followed,[2] the actual evaluation of the integral is a lengthy affair. It may therefore be of some interest to note that it is possible to obtain the desired expression for the orbit energy simply and without the need for performing any integration at all.

In the nonrelativistic limit the kinetic energy T is given by

$$2T=\Sigma p_i\dot{q}_i. \tag{1}$$

Under the same condition, and in the absence of perturbing fields, the orbit is closed and the motion simply periodic. Integrate both sides of Eq. (1) with respect to time over a complete period τ of the motion,

$$2\bar{T}\tau=\Sigma\oint p_i dq_i, \tag{2}$$

where $\bar{T}$ is the average of the kinetic energy. The virial theorem[3] tells us that for inverse square law of force,

$$\bar{T}=-E. \tag{3}$$

The right-hand side of Eq. (2) is the sum of the phase integrals J_i, and the equation can therefore be written as

$$-2E\tau=J_r+J_\theta+J_\phi. \tag{4}$$

A well-known elementary theorem states that the period for elliptic orbits is given by

$$\tau=2\pi a^{\frac{3}{2}}(m/Ze)^{\frac{1}{2}}, \tag{5}$$

where a is the semi-major axis of the ellipse, related to the energy by

$$a=Ze^2/(-2E). \tag{6}$$

Equation (6) can be most simply derived as the average of the two apsidal distances, characterized by $\dot{r}=0$. Combining Eqs. (5) and (6), and substituting in Eq. (4), results in the following expression for the energy in terms of the phase integrals,

$$E=-\frac{2\pi^2mZ^2e^4}{(J_r+J_\theta+J_\phi)^2}. \tag{7}$$

So far the treatment is completely classical. The Bohr model retains the classical expression, but quantizes the phase integrals in accordance with the Sommerfeld-Wilson conditions:

$$J_i=\oint p_i dq_i=n_ih,\ n_i \text{ integral}.$$

Equation (7) shows that the energy is degenerate in the various quantum numbers n_i, depending only on their sum n, the principal quantum number. The final expression for E is therefore

$$E=-\frac{2\pi^2mZ^2e^4}{n^2h^2}, \tag{8}$$

which is the customary nonrelativistic Bohr formula for the energy levels of a hydrogenic atom of atomic number Z.

[1] Semat, *Introduction to Atomic Physics* (Rinehart and Company, Inc., 1948), revised edition, p. 196ff.
[2] See, for example, Goldstein, *Classical Mechanics* (Addison-Wesley Press, Cambridge, Massachusetts, 1951), p. 301f.
[3] Reference 2, p. 69.

The Bragg Method Demonstrated with Sound Waves

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THE experiment demonstrates the familiar Bragg method of x-ray spectrometry[1,2] using ultrasonic waves of about ½-inch wavelength and a crystal model which is of such size that the various "atom planes" are apparent. In this way one is able to perform experiments with a Bragg-type spectrometer and at the same time to observe visually the positions of the atom planes. The apparatus consists of a model x-ray spectrometer, crystal models of desired lattice types, and a detector and source of sound suitable for operation at a wavelength appropriate to the spacing and size of the "atoms" in the "crystals." Models of any crystal-lattice types may be constructed for use with the spectrometer but the principle is adequately demonstrated with the simple cubic type alone. Crystals representing all three types of cubic structure have been made and "analyzed."

The spectrometer is mounted on a wooden base made of a piece of 2-in.×10-in. wood, four feet long. A phonograph turntable is used as the crystal table and its angular displacement is maintained at half that of the movable spectrometer arm by means of a system of belts and pulleys. Both the fixed and the movable arms are constructed of four-foot lengths of "two-by-four." The source of sound is a piezoelectric crystal of the Rochelle-salt type with an effective radiating area of about 2 square inches. It is driven by a power amplifier and Hartley-type oscillator whose frequency is 30 kc/sec. This value was chosen so that the ratio of the wavelength of the sound to the diameter of the wooden balls would be of about the same order of magnitude as the ratio of the wavelength of the x-radiation

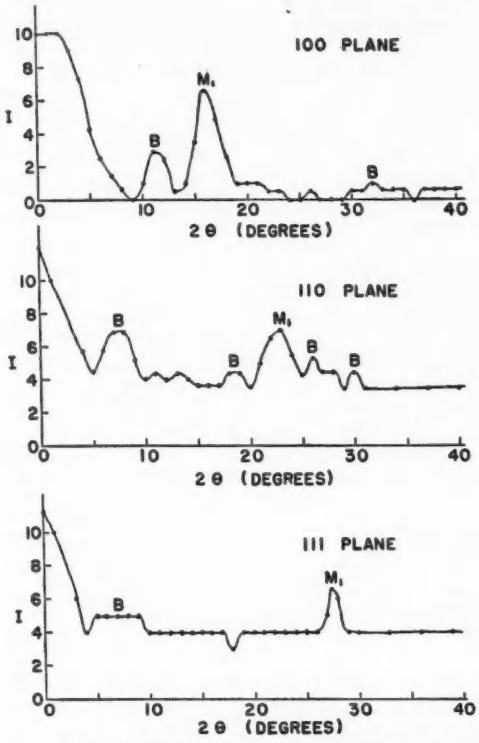

FIG. 1. Graphs of relative intensities I *vs* 2θ (degrees) for the simple cubic model. First-order maxima are labeled M_1; peaks in the background noise which are due to reflections from objects within the room are marked B.

used by Bragg in his original x-ray wavelength determination to the size of the lattice parameter of a NaCl crystal. Shielding and collimation is accomplished by means of pieces of sound absorbent boarding in which holes are cut to accommodate the slightly diverging beam. The positions of all of the shields, for minimum background noise over the operating range of the movable arm, were determined by trial and error. The sound receiver or pickup, which is used to detect the beam after reflection from the crystal model, is a second piezoelectric crystal of the same type as that used for the source. Both the projecter and detector are enclosed in a small box of sound-absorbent material. The output of the detector is amplified and, as the actual intensities of the maxima have no bearing on the results discussed here, relative amplitudes are determined by means of an electronic voltmeter.

Models of the three types of cubic crystal structure were constructed of wooden balls held together by wires of approximately 1-mm diameter, which is sufficiently small that reflection of the sound from them is negligible. Each model occupies a volume of about 1 ft^3 and contains from 30 to 60 atoms from $\frac{3}{4}$ to $1\frac{1}{2}$ inches in diameter. The separation of the 100 planes is about $1\frac{1}{2}$ inches in the models.

By means of the conditions for constructive interference of rays reflected from two adjacent atom planes (Bragg's law), it can be shown that the distance between planes is inversely proportional to the sine of the angle θ which the incident (and reflected) ray makes with the atom planes.[3] If the 100, 110, and 111 planes are considered, the following proportion holds true:

$$d_{100}:d_{110}:d_{111}=(1/\sin\theta_{100}):(1/\sin\theta_{110}):(1/\sin\theta_{111}).$$

From the geometry of a simple cubic crystal it is found that

$$\sin\theta_{100}:\sin\theta_{110}:\sin\theta_{111}=1:\sqrt{2}:\sqrt{3}.$$

The graphs of relative intensities of the reflected beams *vs* values of 2θ, as read from the spectrometer, for each of the three sets of planes studied in the simple cubic structure are shown in Fig. 1. The values of 2θ, θ, and $k\sin\theta$ (experimental), as determined from the graphs, as well as $k\sin\theta$ (theoretical) are given in Table I. For convenience in comparing results, the multiplier k is chosen to make the term $k\sin\theta$ for the 100 plane equal to unity. The construction of the spectrometer limits the accuracy of the values of 2θ to $\frac{1}{2}$ degree.

TABLE I. Comparison of experimental and theoretical results for the simple cubic model.

Plane	2θ	θ	$k\sin\theta$ (experimental)	$k\sin\theta$ (theoretical)
100	16.0	8.0	1.0	1.000
110	23.0	11.5	1.4	1.414
111	27.5	13.5	1.7	1.732

The difference in the relative intensities of the background noise (compare the graph for the 100 plane with those for the 110 and the 111 planes) results from the use of the different voltmeter scales which are necessary to accommodate the amplitudes of the beams reflected from the various crystal planes. The irregularities in the background, labeled B on the graphs, are a result of reflections from objects within the room and from the fact that only a very small number of basic cubes is used in each "crystal."

[1] W. H. Bragg, Nature 91, 477 (1913).
[2] G. L. Clark, *Applied X-Rays* (McGraw-Hill Book Company, Inc., New York, 1940).
[3] Getman and Daniels, *Outlines of Physical Chemistry* (John Wiley and Sons, Inc., New York, 1943).

A Small Scale dc Motor Experiment for the Elementary Laboratory

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IN many physics departments it would be desirable to permit the first-year students to investigate the properties of shunt and series wound dc motors and to experimentally establish the speed *vs* load curves for these two kinds of windings. However, such experiments are at best inconvenient because the Prony brake loading device, which for small motors is not very stable, may shift upon heating. Larger scale equipment is expensive and rarely found in small departments.

Therefore, we present an experiment which may be run at a power level less than 50 watts and which displays all

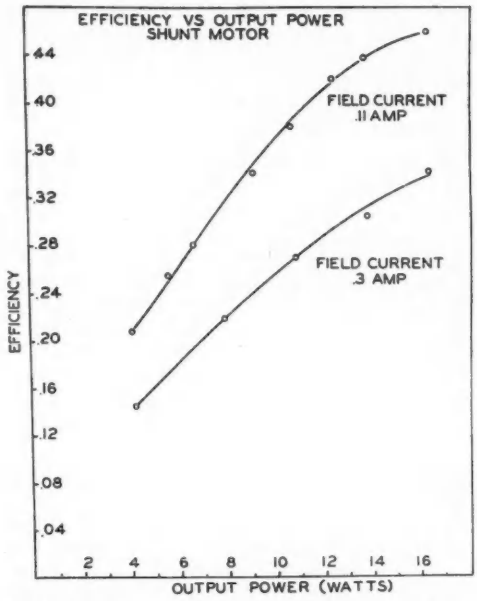

FIG. 1. Efficiency *vs* output power at two different values of field current.

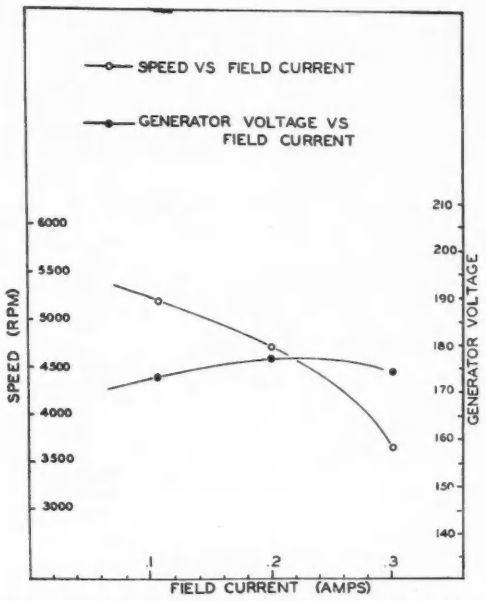

FIG. 2. A graphical comparison of speed *vs* field current with generator voltage *vs* field current.

the principles of its larger scale counterpart. The heart of the experiment is a small 28-volt dynamotor as used in army radio receivers[1] and now obtainable on the surplus market at a cost of about five dollars.

The dynamotor has a common field which is connected internally across the input. Resistance of the field is about 185 ohms and is rated to carry 0.165 ampere. The armature is double-ended with completely separate windings.

Shunt motor.—The first experiment which may be performed is that of a shunt or a separately excited motor. The field leads may be easily disconnected and brought to separate terminals. The field current can be varied with a rheostat and measured with a suitable meter. The same or even another voltage source may supply the armature which can be equipped with meters to record the current and the voltage.

Instead of loading the motor by adding friction drag to the shaft, a load is applied by connecting a variable resistance across the brushes of the high voltage commutator, and allowing the generator winding of the armature to supply power to the resistor. The current and voltage can be measured by suitable meters and the power easily computed. The speed of the shaft can be read by means of a tachometer or by means of a General Radio Strobotac as was done in this case. Comparing commutator ripple to a frequency generator by means of an oscilloscope is another satisfactory method.

By taking readings of input voltage, input current, output voltage, output current, speed; a variety of curves may be plotted.

(a) Efficiency $= \dfrac{\text{output power}}{\text{input power}}$ *vs* output power (Fig. 1).

(b) Speed *vs* output power (Fig. 2).

(c) Output voltage *vs* speed (Fig. 2).

By varying the field current, with a constant load, the speed may be varied. Here it is strikingly demonstrated that a shunt motor runs at increased speed as its field current is decreased, and an opening of field can cause even a motor as small as this to tear itself apart. It is therefore recommended that if used as a student experiment that it be fused rather closely.

The characteristic curve of a shunt wound motor shows fairly constant speed with increasing torque. This curve may be plotted if it is remembered that torque $L=(P_{out}+R_aI^2_{out})/2\pi f$, where P_{out} is the power dissipated in the load, R_a is the armature resistance, I_{out} is the output current, and f is the speed in revolutions/sec.

Series motor.—It is interesting to notice that the rated output current of the high voltage end of the armature is of the same order of magnitude as the rated value of the field current. This suggests connecting these in series and supplying them with a dc voltage source. In this case the unit may be loaded by connecting a variable rheostat across the low voltage terminals. The input current and voltage, output power and voltage and speed may be metered as before. The authors found 125 volts dc a suitable input voltage; approximately 0.2 ampere was drawn at full load. In a similar way efficiency may be plotted against output power. By plotting torque against speed as before, the characteristic of a series motor is shown—a very great torque at low speed and a tendency to run away without load. This poor speed regulation makes it clear why a series motor is never uncoupled from the load.

[1] Westinghouse PE-86 or similar. Available from Communications Equipment Company, 131 Liberty Street, New York 7, New York.

Physics in Negro Colleges—A Progress Report

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SOME of the data on which this preliminary report is based was secured from a study of the bulletins of 42 Negro colleges and 14 small colleges whose enrollments are predominantly white. Other data were secured from questionnaires received from 23 of the 42 Negro colleges consulted and from 8 of the 14 colleges used for comparison. Whereas the Negro colleges and universities include liberal arts colleges, land-grant colleges, teacher training, and technical institutions, with enrollments as high as 2800, the colleges selected for comparison are primarily liberal arts colleges with enrollments less than 1600.

There appear to be no significant differences in the course offerings of Negro colleges as shown by the college bulletins. The introductory courses are followed by the usual intermediate and upper division courses. If there are significant deficiences in offerings, they lie in such courses as Electronics, Modern Physics, Mathematical Physics, and Radiation Physics.

It appears, too, that the Negro student comes into the beginning course in physics with the same three main deficiencies as do other students. In order of their importance, these appear to be deficiencies in elementary mathematical background, in the ability to read and write the English language, and in the mental disciplines which require a vivid imagination, reasoning power, and the ability to correlate facts. In addition to these, however, there are others, such as lack of previous experience in science and with machines, poor study habits, and tepid interest in and appreciation of the subject. One should add to these the fact that many students approach the subject with a fear, which results in a near-paralysis of the mind.

Certain interesting conclusions can be reached from a consideration of the data received. The colleges selected for comparison purposes have an average enrollment of 800 students and thus can be described as "small" colleges. The Negro colleges have an average enrollment of 1300. Thus any deficiencies found in the Negro colleges cannot be credited to smallness of enrollment. The average number of physics teachers in Negro colleges is 1.2 per institution, as compared with 1.9 in the comparison group. In 42 Negro colleges there are 12 teachers with Ph.D. degrees, 23 with M.S. or M.A. degrees, and 10 with B.S. or B.A. degrees. Only 40 percent of the colleges offer a major in physics, as compared with 100 percent for the other group. Ten percent offer neither a major nor a minor. For 1952–1953, in Negro colleges, the budgets for physics equipment and supplies ranged from $260 to $5000, with an average of $2200, as compared with budgets from $200 to $3200 and an average of $1300 in the non-Negro group. The typical Negro college spent nearly twice as much during the current year for physics equipment and supplies, but this may be due to a much greater need for equipment. This is suggested by the fact that one-half of the colleges reported that equipment is adequate for only 50 percent of the courses offered. All of the comparison colleges reported that equipment is adequate for 70 percent or more of the courses offered. For the 10 percent of Negro colleges which do not offer a major or a minor in physics the average enrollment is 1200 and the average budget is $3000. From these data we conclude that in Negro colleges which enroll twice as many students, we have only half as many teachers of physics, some of these devoting only part of their time to physics. In these larger colleges the amount spent in 1952–53 for equipment and supplies was twice as great, but much remains to be done to provide adequate equipment for courses which are offered. Only half of the Negro colleges are offering a major in physics, but funds are being allotted which will enable more of them to do so.

What do we find when we include in the comparison only those Negro colleges which offer the major in physics? The average enrollment of this group is nearly double that of the colleges used for comparison. But the average number of majors per 1000 students enrolled is only 4, as compared with 10 for the comparison group. Again, the budget for the Negro colleges is nearly twice as great. The equipment is considered adequate for only 55 percent of the courses offered, which is still a very low figure. However, since nearly twice as much was spent for equipment, it shows that the deficiency in equipment is being remedied. One-half of the Negro colleges reported that they have facilities for research for the instructor, as against one-third for the other group. All Negro colleges reported that job opportunities are excellent for Negro physicists and that no difficulties have been experienced in placing their graduates. Many of these graduates have obtained advanced degrees from universities across the nation. One must conclude, however, that even in colleges where a major is offered there remains much to be accomplished in securing adequate equipment and in increasing the number of majors.

Some universities deserve special commendation in the light of the average situation found in Negro colleges. One reports an expenditure of $50 000 for physics equipment for their new science building; another reports $17 000. Still another reports the completion of a million-dollar science building and the expenditure of $5000 for physics equipment. At another university which has recently begun to give a Master of Science degree a total of 30 graduates have been employed in industry, civil service, and teaching. This university reports current research projects underway on the Hall effect, ultrasonics, and microwaves. Still another university which offers the Master of Science degree lists 39 graduates, some of whom have attended Harvard, St. Louis University, Michigan, Iowa, Pennsylvania State, and The University of Bordeaux. This university reports current research projects in infrared and molecular structure, which are supported in part by grants from the Research Corporation and the U. S. Public Health Service. Papers have been published in *The Journal of Chemical Physics* and *The Journal of the American Chemical Society*.

In conclusion, we believe that certain things are evident from this preliminary sampling. The Negro colleges are trying to offer the same undergraduate courses in physics as one finds in a typical liberal arts college. The equipment which they have is still inadequate for the courses offered, but expenditures are being made to correct this situation.

Perhaps this has been the reason only half of the colleges have offered a major in physics. The deficiencies of the student are of the same kind as those for students elsewhere though possibly greater in degree. Those majors who have been graduated have done reasonably well both in graduate study and on jobs. A few of the colleges are doing a respectable job, but the number of majors is much too small.

A Modified Barlow's Wheel

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BARLOW'S Wheel is a metal disk mounted between the poles of a permanent magnet so that the magnetic field is perpendicular to the face of the disk. A bearing at the center of the disk allows it to turn when a direct current along a radius, and also perpendicular to the field, experiences a force resulting from its interaction with the field. Electrical connections are made to the edge of the disk through a trough of mercury and to the center through the bearing.[1]

Conventional wheels use solid disks and require large currents for their operation.[2] They are tested at twenty amperes.[3] As soon as rotation of the solid disk takes place, eddy currents exist which produce a braking effect proportional to the speed of rotation. In fact, this same apparatus is used to demonstrate the braking effects of eddy currents.[4]

Radial cuts on the disk constitute the major modification. As shown in Fig. 1, these cuts extend from the edge of the disk along radii until well through the region occupied by the magnetic field. They serve to reduce the eddy currents to a very small value. As a result the braking is reduced, allowing much smaller currents (about 1.5 amperes minimum) to produce very much larger rotational speeds; a double gain in demonstration value.

A second modification is the design of the bearing. Since the slotted disk runs on smaller currents, some efficiency loss can be tolerated in the interest of convenience both in providing the bearing and supporting the disk. Hardened surfaces or pivots are not necessary and the simplest sort of arrangement suffices. Since this is true, it is possible to provide for the rapid interchange of disks. Both solid and slotted disks can then be used and the contrast in operation demonstrated. Furthermore, it is possible to use disks as large as the lecture room requires.

The third modification is the use of a magnetron magnet of about 2000 gauss such as many physics departments have secured from war-surplus stocks. The strength of this magnet no doubt contributes to the reduction of the minimum current required, but the comparison of the speeds of identical disks except for the slotting shows definitely that the major factor in this reduction is the decrease of the braking.

This modified wheel will run continuously for many hours when connected to a small two-volt storage cell such as Willard No. 9–45 Z in series with about one ohm of resistance provided a film of fine oil is put on the surface of the mercury to inhibit oxidation. But if only occasional operation for short periods of two or three minutes duration is desired (that is, for typical demonstration use), the source can be a flashlight cell or a No. 6 dry cell. It is also possible to replace the mercury trough by a piece of brass shim stock when operation is not continuous.

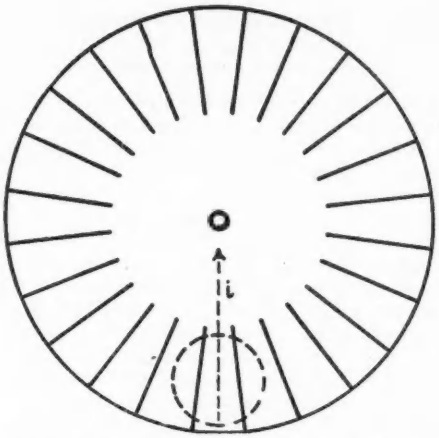

FIG. 1. Full face diagram of disk for modified Barlow's Wheel. Radial lines represent the radial cuts, dotted arrow represents direction of current flow, and the dotted circle represents the extent and position of the magnetic field.

[1] Richard M. Sutton, *Demonstration Experiments in Physics* (McGraw-Hill Book Company, Inc., New York, 1938), No. E-136, p. 306.
[2] Central Scientific Company, Catalogue number 79630 or Welch Scientific Company, Catalogue number 2487.
[3] Kenneth F. Wessling (Design Engineer—Central Scientific Co., Chicago), (private communication).
[4] Richard M. Sutton, *Demonstration Experiments in Physics* (McGraw-Hill Book Company, Inc., New York, 1938), No. E-225, p. 343.

Elimination of Variables in the Biot Equation

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IN Fig. 1 a conductor AB carrying a current I is on the x axis of a coordinate system. The Biot equation gives the magnetic induction ΔB at point $P(y=r, z=0)$ due to I in Δx only. Following Sears we write the Biot law as in Eq. (1),

$$\Delta B = (\mu_0 I/4\pi)(\Delta x/s^2)\sin\phi. \qquad (1)$$

Here ΔB (perpendicular to the plane of the figure and outward) is in webers per square meter if I is in amperes and s and Δx are in meters, while μ_0 is written for $4\pi 10^{-7}$. In order to evaluate B due to the length AB of the straight

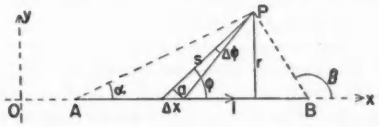

FIG. 1. A steady current I flows in a wire AB of finite length which lies along the x axis. It is desired to find the magnetic induction at a point P distant r from the axis of the wire. The distance and angles r, α, β are, of course, constant; s, a, ϕ, and x are variables.

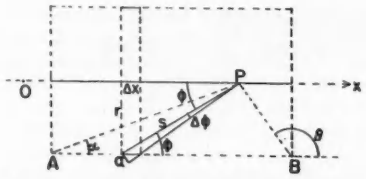

FIG. 2. A steady current I flows in the coils of a helix whose over-all outline is the large dotted rectangle AB. It is desired to find the magnetic induction at a point P on the axis of the helix. The quantities r, α, β are constants; s, ϕ, x, a are variables.

conductor, we form the definite integral of ΔB between proper limits. But, before we can integrate, we must eliminate two of the three variables x, s, and ϕ. It is conventional to do this by trigonometric relations, making use of such expressions as $\tan\phi$, $\cot\phi$, $\csc^2\phi$, or $1/\cos^3\phi$, or perhaps to use $(x^2+r^2)^{\frac{1}{2}}$. But we may notice that in Fig. 1 the product of the base Δx and the altitude r is double the area of the small triangle with the small angle $\Delta\phi$. Also in Fig. 1 and in Fig. 2 it appears that double the area of this triangle approaches sa or $s(\Delta\phi s)$ as $\Delta\phi$ becomes smaller toward zero. Therefore

$$r\Delta x = s\Delta\phi s, \quad \text{or} \quad \Delta x/s^2 = \Delta\phi/r. \tag{2}$$

Therefore

$$\Delta B = (\mu_0 I/4\pi r)\sin\phi\Delta\phi. \tag{3}$$

Then the integral from $\phi=\alpha$ to $\phi=\beta$ gives

$$B \text{ at } P \text{ due to } I \text{ in } AB = (\mu_0 I/4\pi r)(-\cos\phi)_\alpha^\beta. \tag{4}$$

The same equation of area serves to eliminate two of the three variables in the expression for ΔB at P on the axis of a helix due to the current in the turns in the length Δx only. In Fig. 2, Δx is laid off on the axis of the helix AB. If the helix has n turns per unit length the total current in the length Δx is $nI\Delta x$, and

$$\Delta B = (\mu_0 nI/2)(r\Delta x/s^2)\sin\phi. \tag{5}$$

But, as before, $r\Delta x/s^2 = \Delta\phi$, so that

$$\Delta B = (\mu_0 nI/2)\sin\phi\Delta\phi. \tag{6}$$

We have only to integrate $\sin\phi\Delta\phi$ as before.

Some textbooks avoid the integration for B on the axis of a solenoid by making use of the amount of energy required to transport a magnetic pole completely around a conductor carrying a current. But in the many books using integrations, that I have consulted, I have not found this simple and obvious elimination by use of area, either for the straight conductor or for the helix.

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LETTERS TO THE EDITOR

Particle Properties of Radiant Energy in Wave Guides

SINCE the publication of my paper, "Particle Properties of Radiant Energy in Wave Guides,"[1] Professor Louis de Broglie, Academie des Sciences, Paris, kindly sent me his book, *Problèmes de propagations guidées des ondes électromagnétiques*,[2] with the author's compliments and the following note: ". . . je me permets de vous adresser ci joint le deuxième édition de mon petit ouvrage sur la propagation guidée des ondes électromagnétiques où vous trouverez pages 34 à 37 des considérations qui se rapprochent un peu des vôtres. . . ."

I feel indebted to Professor de Broglie for drawing my attention to his admirably written book, and regret that owing to my ignorance I did not quote it as reference.

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[1] W. R. Raudorf, Am. J. Phys. 21, 25 (1953).
[2] Louis de Broglie, *Problèmes de propagations guidées des ondes électromagnétiques* (Gauthier-Villars, Paris, France, 1951).

Clarification of Some Elementary Concepts in Electricity and Magnetism

THE statement is often made[1] that lines of force do not exist. Now, a line of force is a line whose tangent at any point gives the direction of the field intensity at that point. Insofar as electric and magnetic fields exist and have reality, they have vector properties at each point. Therefore, a line of force, which is the envelope of a group of these vectors, is an actual property of the field and is not merely a device to demonstrate better the nature of the field. Of course, if further properties are given these lines of force, such as elasticity, attractive forces, etc., then we are moving away from the actual description of the field and substituting partially false analogies. But the lines of force have as much existence as the fields themselves.

A second error which is quite common is found in textbooks such as those by Harnwell[2] and Page and Adams[3] on electricity and magnetism, although less recent books by Jeans[4] and Planck[5] clearly avoid this error. Both of the former authors consider tubes of force as the sum of many lines of force. This error is illustrated by the letter referred to above. "The lines of force in a field should be infinitely dense . . . ," and ". . . we use the density of lines of force as a measure of field intensity." I think by this time it should be clear that an infinity of lines do not make a volume, not even an infinitesimal volume. The vector tangent to a line of force at a given point gives the direction of the field at that point. The magnitude of the field at that point gives the magnitude of the vector. The magnitudes may be represented by a hypersurface. Sometimes the field intensity at a point is represented by the area density of the tubes of force at that point in the direction of the line of force at that point. However, a sharp distinction must be

made between a tube of force, even though infinitesimal in width, and a line of force. It is impossible to define field intensity in terms of lines of force.

The definition of lines and tubes of force should be independent of the particular law they describe. For instance, could lines and tubes of force be used to describe an inverse cube single source? Or are they restricted only to the inverse square law? None of the authors mentioned discuss this point. However, we can easily see that the concept of lines of force can be applied to any continuous vector field. But the concept of tubes of force cannot be applied as a measure of the intensity. The area density of the tubes of force at any point falls off inversely as the square of the distance from a point source. In order that tubes of force may describe an inverse cube field they must terminate in free space in a continuous manner in order to fall off sufficiently rapidly in density. This will give a field everywhere discontinuous. (Every infinitesmal volume of the field will be zero in at least one internal point and nonzero in at least one internal point.) This clearly brings out the difference between lines and tubes of force. We cannot then, as Jeans does, identify lines on the tube boundary as lines of force except in the inverse square case. The lines of force are continuous for continuous vector fields, while the tubes of force are continuous only for the inverse square law.

Both of the more recent authors leave themselves open to misinterpretation in their discussion of the self-pressure of a charged conducting surface. The equation is $F_s=q_s^2/2\kappa_0$ (mks units), where q_s and F_s are, respectively, the surface charge density and the self-pressure at some point on the surface of the conductor and κ_0 is the permittivity of free space. The field at the point on the surface of the charged conductor is given by $E=q_s/\kappa_0$. The force on the charge dq at this point is given as $dF=\frac{1}{2}E(dq)=\frac{1}{2}q_s dq/\kappa_0$. From this $F_s=q_s^2/2\kappa_0$. The factor $\frac{1}{2}$ arises from the fact that only one-half of the field acts upon dq. The other half arises from dq and thus cannot act back upon its own source. (Jeans very carefully points out the necessity of dividing the field into two parts in this and similar problems.) Thus, since q_s refers to the charge density at a given point, E is misinterpreted to be the field which arises wholly from the q_s at the given point. If this were so, $F_s=0$. Actually one-half of it arises from the charges on the remainder of the conductor. It is only this half of the field which acts upon dq.

A similar misinterpretation arises with the concept of self-induction. Strictly speaking, there is no such phenomenon as true self-induction—at least on the macroscopic level. The magnetic field can act back upon its current source no more than the electric field of a charge can react back, in the usual theory, on its source. Jeans clearly points out that one filament of the source current reacts upon the rest of the current through its magnetic field but does not react back upon itself. Thus, strictly speaking, we still have mutual-induction, even though the term, self-induction, is used because the filament currents physically form one current. The question might then be asked: suppose we have an infinitesimally wide current—is there a nonzero induction here? The answer is yes, because every infinitesimal can be further divided so that one part then will act upon the rest of the current. The only possible case might be where the current is an actual line, a one-dimensional flow. However, this case is excluded since actual space is 3-dimensional. It might be well to emphasize this point. There is a distinct mathematical difference between infinitesimals and points. Surface charge density is defined as charge per unit area, but it actually occupies a surface volume of infinitesimal thickness. The lateral density here approaches infinity; $dq=q_s ds=q_v dl ds$, where dl is the thickness. Since ds is a second-order infinitesimal and q_s is finite, q_v must approach infinity, which means that the lateral density must approach infinity. In actuality, of course, $dq=q_v \Delta l ds$. But then, $q_v \Delta l$ is not, strictly speaking, the surface charge density.

A less serious error (because it is only mathematical) appears in Harnwell,[1] Slater and Frank,[6] and Stratton[7] in the derivation of the boundary conditions at the interface of two dielectrics. If no free charge is on the interface the normal component of the displacement vector is continuous across the interface. The derivation consists of applying Gauss' theorem to an infinitesimal right cylinder which is across the interface. A necessary step in the proof is to show that the net flux through the curved surface of the cylinder is zero. This is done by shrinking the height of the cylinder to zero so that the flux can only go through the faces of the cylinder. However, then we no longer have a cylinder but only the two faces coinciding at the interface. We then can no longer apply Gauss' theorem since there is no longer a volume to which to apply it. The proof then breaks down. If instead of shrinking the height to zero, we merely cut it to a small fraction of its original size; its order of magnitude would not have changed and there still would be flux through the sides. The correct argument is as follows: the sum of the fluxes through the faces and the curved surface of the cylinder is zero. Since the area of the cylinder faces and the height of the cylinder are independent variables, the flux through the faces and the curved surface must separately equal zero. From this, the boundary condition follows. The same type of argument holds for the continuity of the tangential components of the electric field at a dielectric surface.

In the more recent textbooks Ampere's law of force between circuits is stated in terms of infinitesimals without stating that the resulting infinitesimal forces are not necessarily the actual and correct ones. In fact, in this form Newton's third law does not hold. Either complete circuits must be taken or the displacement currents must be introduced to explain this and get the correct form. Both Jeans and Planck avoid this error, although they do not discuss the point.

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[1] E.g., Irving L. Kofsky, Am. J. Phys. **20**, 375 (1952).
[2] G. P. Harnwell, *Principles of Electricity and Electromagnetism* (McGraw-Hill Book Company, Inc., New York, 1949), second edition.
[3] L. Page and N. I. Adams, *Principles of Electricity* (D. Van Nostrand Company, Inc., New York, 1949), second edition.
[4] J. H. Jeans, *The Mathematical Theory of Electricity and Magnetism* (University Press, Cambridge, England, 1927), fifth edition.
[5] M. Planck, *Theory of Electricity and Magnetism*, Vol. III of *Introduction to Theoretical Physics* (Macmillan and Company, Ltd., London, 1932).
[6] J. C. Slater and N. H. Frank, *Electromagnetism* (McGraw-Hill Book Company, Inc., New York, 1947).
[7] J. A. Stratton, *Electromagnetic Theory* (McGraw-Hill Book Company, Inc., New York, 1941).

ANNOUNCEMENTS AND NEWS

Book Reviews

Selected Science Teaching Ideas of 1952. Edited by R. WILL BURNETT. 57 pp. National Science Teachers Association, Washington, D. C., 1952. Price $1.50.

This richly illustrated booklet is an outgrowth of the program of Recognition Awards for Science Teachers sponsored by the American Society for Metals and conducted by the Future Scientists of America Foundation of the National Science Teachers Association. Fifty-seven science teachers reported on their own "best practices and most effective techniques" and, from their reports, 15 were selected for inclusion in the book. The editor hopes that future issues will bring to light practices not yet mentioned.

The principal theme is the early discovery and identification of the gifted science student and the creation of conditions appropriate for his growth. The contributors describe their provisions for special courses, project work, laboratory-squad activities, field trips, visits to museums, etc. Among the projects mentioned are some that are quite intricate, such as work with microphotography and microprojection, design of scintillation counters, the construction of a 0.5-Mev cyclotron, and research in nuclear reactions. The students selected for this work plan and carry through these difficult assignments with conspicuous success, win prizes and awards in local, state, and national contests, and sustain their interest in science in their college work.

The reviewer endorses the wisdom of this early discovery and stimulation of science-gifted students. He would suggest, however, that *general* excellence and a high level of accomplishment in *all* of the basic high school subjects form a better guide to future science work than do marks in science and mathematics alone. Competence in the use of English—both written and spoken—and an approach to history as a record of *ideas*, are both important in the lives of our future scientists. Unfortunately, both have been neglected.

The *Selected Science Teaching Ideas of 1952* points the way to better work in science. It does this enthusiastically and persuasively. It certainly deserves wide reading and discussion, and above all, emulation. If America is to play her role of leadership effectively, she must discover, utilize, and encourage the more talented in her midst.

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Principles of Modern Acoustics. GEORGE W. SWENSON, JR. Pp. 222+vii, Figs. 71, 15.5×23.5 cm. D. Van Nostrand Company, Inc., New York, 1953. Price $4.00.

It is a usual practice at many universities to restrict serious instruction in acoustics to a single course at the junior or senior level. Under these circumstances it is always difficult to know what material to exclude. In this textbook, which is written at the senior level, the author has chosen to exclude from discussion all nonelementary aspects of the media in which sound is propagated and to concentrate on electrical, mechanical, and acoustical systems in their application to the production and reproduction of sound. Moreover, he has concentrated on methods of analysis introducing only a minimum number of applications by way of illustration.

The nine chapter headings are: Oscillations in Lumped Parameter Systems, The Vibrating String, The Vibrating Membrane, Acoustic Waves, Radiators, Acoustic Circuits, Architectural Acoustics, Speech and Hearing, and Approximate Methods for Acoustics Problems.

Considerable use is made of the electrical analogy, the force-current, velocity-voltage system (Firestone or mobility analogy) being used principally. A brief exposition of some of the essentials of circuit analysis is given in the first chapter. The mks system is used. The topics covered and the nature of the treatment are such as to make the text of principal value to engineering students.

Clearness of presentation, conciseness and adequate treatment of methods of analysis are the text's best features. Unfortunately, it is marred by errors of fact, omission and emphasis. It is doubly unfortunate, since the number of modern texts in acoustics is small and additions are to be encouraged.

At the risk of belaboring a point, the rest of the review will be devoted entirely to a discussion and listing of the points which this reviewer found disturbing.

An equation is given (the reader is referred to Crandall, *Vibrating Systems and Sound*, for the derivation) for the acoustic impedance of a tube sufficiently narrow so that the radius is somewhat smaller than the viscous wavelength. Apparently, however, the author overlooks the requirement on the radius, states it to be a general result applicable to tubes of arbitrary radius and arrives at the mistaken conclusion that the mass reactance of large-radius tubes of cross section S, and length l, containing gas of density ρ, is $4j\omega\rho l/3S$ (the proper numerical factor is unity but the author apparently regards the 4/3 factor as being more nearly correct). In discussing the flexible string, it is calculated that the input impedance of a quarter-wavelength string with a free end is infinite. This leads to the statement that "no finite force at the input end could produce even a small periodic displacement of the desired frequency." It is not clear whether the author is referring to the displacement of the input end of the string or to any arbitrary point on the string. If it is the former, then the statement is correct, but a half-page discussion of this "absurd result" is hardly justified in a book (one of whose keynotes is brevity) which presumes that its readers already have an understanding of the significance of infinite impedances in electrical theory. On the other hand if it is the latter of the two alternatives then the statement is incorrect. The displacement is nonzero at all points other than the input end. This error would not have occurred if the more general quantity, the transfer impedance, had been introduced.

Those with a working knowledge of acoustics would take exception to the diagram of an impedance tube (on page 91) showing an open slot running half the length of the tube; or the unqualified statement that "the electrical output of a condenser microphone is inherently very low"; or to classifying magnetic telephone receivers along with condenser microphones and drum heads as examples of applications of flexible membranes; or to the author's method of increasing the transmission loss through a wall by requiring that "the walls of the room should be rigid enough so that the resonant frequencies of the wall themselves will be outside the range of audible frequencies."

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Introduction to Geometrical and Physical Optics. JOSEPH MORGAN. Pp. 450+xii, Figs. 275. 15½×23½ cm. McGraw-Hill Book Company, Inc., New York, 1953. Price $6.50.

Dr. Joseph Morgan, Professor of Physics at the Texas Christian University, intends his textbook "to serve as a basis for an intermediate course for students at their sophomore or junior level. . . ." It is aimed to fulfill the needs of the physics major as well as of the student who seeks a general comprehensive treatment of the field." The book assumes a knowledge of general physics and analytical geometry; however, the physics material is developed from elementary principles. This partial duplication of material already studied in an introductory physics course is advantageous to the average student. In addition it makes the textbook useful and interesting to the nonstudent reader. The usual intermediate textbook, starting from basic principles, yet developing the subject in some detail, fills a definite need between advanced textbooks beginning at a high level and elementary textbooks which can hardly get off the ground. Morgan has sufficiently developed the subject for the book to serve admirably juniors, seniors, and first-year graduates.

A large part of the book is written without calculus. Many of us who lean on calculus as on a crutch will be surprised to see how much can be done with analytical geometry plus ingenuity. To emphasize this certain ideas are developed in parallel, half-width columns, one using calculus, the other not. This innovation makes the book usable by students of varying mathematical preparation. Though the average student will probably study only one of the two developments, this dual presentation in some dozen sections should be of great value to instructors.

The book devotes about the same amount of space to geometrical and physical optics, concluding with two chapters on spectra and photon optics. The nice balance between the two main divisions of optics makes it difficult to tell which the author prefers. In scope and detail of material this book compares very favorably with three other fairly recent textbooks covering the same material at the same level. In two respects, however, Morgan's book is outstanding: it has an exceptionally complete index, averaging five items per page, which is twice as many as these other comparable textbooks; and there is a wide selection of problems, significantly more, relative to its size, than the other textbooks. Since the problems often develop the text material in greater detail, the index includes references to problem material. An example of the completeness of development is the chapter on "Mirror and Lens Aberrations" where this important subject, with its inherent mathematical difficulties, is clearly explained.

Geometrical optics, dealing with the interrelationships of two spaces (object and image), has its own special problems of coordinate geometry. Since it is not always possible to use a single coordinate system without letting the equations get unwieldy, the student is often confused by the sign conventions which are usually different for the object and image spaces. To minimize this difficulty Morgan uses sign conventions which are the same for both object and image spaces. He therefore needs only one coordinate system, having its origin at the vertex, for single surfaces and thin lenses. For thick lenses the sign conventions remain the same though the origins (principal points) are now in general separated. The conventions other than distances along the axis, such as lateral distances, angles, and radii of curvature, are similar to those found in most other contemporary American texts.

Morgan treats reflection as a special case of refraction. In this way the refraction equation for a single surface, with the sign conventions originally assumed, can be used for thin mirrors. However, in summarizing the sign conventions, by making realness and virtualness the basis of classification, Morgan finds it necessary to have a different set of signs for mirrors and lenses. If position, instead of character, had been retained as the basis of classification, all conventions would hold for all systems. This general applicability of the basic sign conventions and equations to any optical system whatsoever can be most easily appreciated by a discussion of ideal optical imagery as developed by Maxwell, Abbe, and Southall. It is also clear, from a study of this theory, why object-image position is more fundamental than character. It is to be regretted that Morgan does not consider this material; it has a place in an intermediate textbook and lends itself to easy development by analytical geometry.

Since this is a book on physics, and not mathematics, the drawings should represent, unless too inconvenient, the state of affairs in the physical world. Morgan realizes this since many of his drawings are laid out to agree with the physical situation. When this is not possible he carefully marks them "not to scale." Some drawings, however, seem to have been made without this in mind. For example, the figure showing total internal reflection cannot represent the physical situation intended. In some of these drawings the defects are easily noticed by eye. For the average student this state of affairs is of no consequence; for the person who studies the drawings carefully it is somewhat disturbing.

On the whole Professor Morgan has written a book which adequately fulfills the purpose for which it was intended. It is clearly and interestingly written, and quite detailed in its development. It can be highly recommended both as a textbook and as a reference book.

RICHARD HANAU
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Photoelectric Tubes. Second Edition. A. SOMMER. Pp. 118+viii, Figs. 27, 11×17 cm. John Wiley and Sons, Inc., New York, 1952. Price $1.90.

An earlier edition of this member of the Methuen Series bore the title *Photoelectric Cells*. This book was critically reviewed by W. B. Nottingham who objected to the title, since it dealt entirely with photoelectric tubes, and who pointed out the need for a modern treatment of the theories of photoelectric processes. A new title adequately meets the first objection and a new chapter, by S. Rodda, attempts to satisfy the second. In view of our present knowledge of the photoelectric process in both metals and semiconductors this chapter could easily be increased to double its present size. Chapter III which comprises over one fourth of this book is an excellent source of information regarding details of preparing complex photoelectric surfaces. This type of information is available elsewhere only in the original journal articles to which frequent references are made. Principles involved in matching the spectral characteristics of light sources and photocathodes and the general characteristics of vacuum, gas, and multiplier type photocells are dealt with in subsequent chapters. Some specific applications of photocells are discussed in the final chapter. This reader would have preferred a less qualitative treatment of the subject matter in general and objects specifically to expressing the velocity of an electron in volts, page 18, and to the use of a variable factor 12 420 on page 8 and 12 000 on page 18 to relate wavelength and potential.

ALBERT S. EISENSTEIN
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Physics for Science and Engineering Students. W. H. FURRY, E. M. PURCELL, AND J. C. STREET. Pp. 694 +viii, Figs. 613, 18×26 cm. The Blakiston Company, New York, 1952. Price $6.50.

This textbook is intended specifically for science and engineering students. The format of the book is somewhat unusual in that there are two columns to the page and all of the problems are collected in a single list at the end of the book. The answers are given for about half of the problems. Calculus is used throughout. In the earlier part of the book the use of the calculus is somewhat restricted to the statement of definitions and laws. In this part the calculus statements are explained in some detail in order to ". . . impart a sense of the meaning of calculus in physics. . . ." Calculus is used more freely in the later parts and a few of the problems require the application of calculus.

The authors have purposely included considerably more material than can be included in the usual one-year course. This is done since ". . . a book can be most useful as a text, as well as for reference, by including a greater amount of material, from which each teacher can make his own selection." For this reason the book includes some material which is normally given in intermediate courses.

The book gives a good clear presentation of the basic physical principles. The statements and principles are accurate, clearly and carefully stated. There are many drawings throughout the book, but relatively few photographs.

The mechanics begins with kinematics and makes use of derivatives and definite integrals. This is followed by Newton's laws of motion. The absolute cgs and the "British-Engineering" systems of units are used with emphasis on the cgs system. The more convenient units of force of gm-wt and kg-wt are used and their meaning carefully explained. The "British-Engineering" system is used without introducing a new unit of mass.

The important relation that the work done on a body by the resultant of all forces acting on it is equal to the gain in kinetic energy is derived for the case of a constant force without stating so explicitly. It seems to the reviewer that this relation could just as well be derived for the general case of a variable force since the work done by a variable force has been discussed in a previous section. The principle of conservation of energy is stated only in terms of mechanical energy for conservative forces. In a book designed for engineers it would seem more desirable to give a statement of the law of conservation of energy that includes the work done against friction. Work done against friction is given little attention in the text and problems.

The Celsius temperature scale is used in place of the centigrade scale as decided in 1948 by the Ninth General Conference on Weights and Measures. The approximations which are made in the equations on linear and volume expansion are carefully and clearly explained as is the case throughout the entire book. Of the more advanced material sections are included on equipartition of energy and specific heats and evidence from specific heats for quantum theory.

In electricity and magnetism the cgs system is used predominantly. The practical and emu systems are also used. In Appendix II is given a discussion of the rationalized mks system and the formulas which may be substituted for the corresponding cgs formulas in the text if it is desired to use the mks system. This perhaps makes the book somewhat more flexible, but is questionable from the standpoint of teaching technique. It does, however, give the interested student an opportunity to obtain information on the various systems of units.

The magnetic properties of matter are discussed on the basis of magnetic poles rather than Amperian currents. On the basis of the dipole model the text states that, "From the point of view of this model, poles of a magnet are regions of excess magnetic 'charge' of one sign or another." Even though the text carefully explains how the magnetic poles arise on the basis of the dipole model, the use of the concept "magnetic charge" seems to the reviewer as unnecessary and adds nothing to the understanding of the magnetic properties of matter.

Considerably more detail than is found in the usual elementary text is given in diffraction and color. Refraction at a single spherical surface is discussed before the topic of thin lenses.

The last four chapters deal with the quantum, the atom, the nucleus, and cosmic rays and elementary particles. There is an excellent introduction to the quantum theory,

clearly pointing out the inadequacies of the classical theories. Nuclear physics is covered quite thoroughly for an elementary text. The detection of nuclear radiation by means of ionization chambers, Geiger counters, cloud chambers, and photographic plates is clearly presented. In discussing radioactivity no mention is made of the fact that beta-rays have a continuous distribution in energy while alpha-rays and gamma-rays have discrete energies.

As stated before, the textbook is intended for science and engineering students. For engineering students it would seem desirable to use the mks system in electricity and the mks and "British-Engineering" systems in mechanics. The electrical engineers have rather generally accepted the mks system and for this reason it seems reasonable to use this system in an elementary text designed for engineering students.

The textbook is comprehensive, thorough, and emphasizes fundamental principles. The exposition is good with careful and clear definitions. The development of physical ideas and concepts is very good. There is considerably more material than can be covered in the usual course, which gives the teacher the opportunity of making his own selection of material, and also gives the interested student a book with additional information. There is a good selection of problems. The book is a real contribution to the teaching of elementary physics.

There are the usual errors expected in a new textbook and most of these are rather obvious.

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Publications Received

The descriptive phrases are quotations from publishers' advertisements, or from authors' prefaces.

Advanced Experiments in Practical Physics. Second Edition revised. J. E. CALTHROP. 142 pp. William Heinemann, Ltd., London, 1952. 10s. 6d. A series of fifty-five experiments designed for the Honours Degree course in physics.

Advanced Mechanics of Materials. Second Edition. FRED B. SEELY AND JAMES O. SMITH. 680 pp. John Wiley and Sons, Inc., New York, 1952. $8.50. Second edition is essentially a new book . . . prepared primarily for advanced undergraduate and first-year graduate students in engineering.

Advances in Geophysics. Edited by H. E. LANDSBERG. 362 pp. Academic Press, Inc., New York, 1952. $7.80. In this first volume several review articles, showing the advances made in geophysics, appear.

American Association of Physics Teachers and Colloquium of College Physicists. Audio-Visual Aids Committee of AAPT. 450 pp. $2.00. Meetings at the University of Iowa, June 11–14, 1952.

An Annotated Bibliography of Selected References on the Solid-State Reactions of the Uranium Oxides. S. M. LANG. 95 pp. National Bureau of Standards, Circular 535, 1953. $0.30 from U. S. Government Printing Office, Washington 25, D. C.

Animal Biochromes and Structural Colors. DENIS L. FOX. 379 pp. Cambridge University Press, New York, 1953. $11.00. Professor Fox writes his early chapters on the physical aspects of color in living beings, and, later, on those aspects with a chemical basis.

Annual Review of Nuclear Science. Volume 2. Committee on Nuclear Science. 429 pp. Annual Reviews, Inc., Stanford, California. $6.00. Second in a series of annual review volumes planned to cover the most important developments in the fields of nuclear science each year.

Annual Review of Physical Chemistry. Volume 3. Edited by G. K. ROLLEFSON. 416 pp. Annual Reviews, Inc., Stanford, California, 1952. $6.00.

Atomic Energy Levels, Volume II. CHARLOTTE E. MOORE. 227 pp. National Bureau of Standards, Circular 467, 1952. $2.25. Contains data on 152 spectra of elements having atomic numbers 24 through 41.

Atoms, Men, and God. PAUL E. SABINE. 226 pp. Philosophical Library, New York, 1953. $3.75. The work of a Protestant layman, a research physicist, who shares with many people of similar religious background the problem of reaching rational religious beliefs in this "age of the atom."

Basic Body Measurements of School Age Children. W. EDGAR MARTIN. 74 pp. U. S. Department of Health, Education, and Welfare. Obtainable from the School Housing Section, Office of Education. A Handbook for school officials, architects, and design engineers in planning school buildings, furniture, and equipment.

Birth and Death of the Sun. Second Edition. GEORGE GAMOW. 219 pp. The New American Library of World Literature, Inc., New York, 1952. $0.35 (Mentor Edition). Since the first publication of this book twelve years ago, considerable progress has been made in our understanding of stellar evolution and the formation of planetary families.

Calculus. C. R. WYLIE, JR. 565 pp. McGraw-Hill Book Company, Inc., New York, 1953. $6.00. First course in calculus, including an introduction to differential equations.

Can I Be an Engineer? 20 pp. Department of Public Relations, General Motors, Detroit 2, Michigan. Aimed at the student in his early years of high school, attempting to interest him in engineering and in taking the proper high school subjects to prepare him for an engineering course in college.

Cardano, the Gambling Scholar. OYSTEIN ORE. 249 pp. Princeton University Press, Princeton, New Jersey, 1953. $4.00. Story of Cardano's life . . . also an account of Renaissance scholarship and university life. "The Book on Games of Chance" is translated from the Latin by Sydney Henry Gould.

Careers for Civilians. 55 pp. Department of The Air Force, Headquarters United States Air Force, Washington 25, D. C. A guide to air force opportunities for scientists, engineers, administrators, and technicians.

Charters of Freedom. (The Declaration of Independence, The Constitution, The Bill of Rights). 12 pp. National Archives Trust Fund Board. $0.25 from National Archives, Washington 25, D. C.

Circuit Theory of Electron Devices. E. MILTON BOONE. 483 pp. John Wiley and Sons, Inc., New York, 1953. $8.50. Book is based on author's observation that the beginning student can best achieve an understanding of a new device through a study of its over-all circuit behavior.

College Physics Review. ROBERT L. WEBER. 72 pp. 1953. $0.75 from W. B. Keeler Book Store, State College, Pennsylvania. Represents a selection of tests given since 1950 which any student may purchase for his own convenience.

Comets and Their Origin. R. A. LYTTLETON. 173 pp. Cambridge University Press, New York, 1953. $5.00. The author sets out the known observational facts about comets, then accounts for their origin.

Computing Methods and the Phase Problem in X-ray Crystal Analysis. Edited by RAY PEPINSKY. 390 pp. X-ray Crystal Analysis Laboratory, Pennsylvania State College, State College, Pennsylvania, 1952. $7.50. Papers from a conference held in April, 1950 at Pennsylvania State College.

Conformal Mapping. Translation of fourth edition. L. BIEBERBACH, translated by F. Steinhardt. 234 pp. Chelsea Publishing Company, New York, 1953. $2.25.

Core Curriculum Development, Problems and Practices. GRACE S. WRIGHT. 104 pp. Federal Security Agency, Bulletin 1952, No. 5. $0.30 from U. S. Government Printing Office, Washington 25, D. C.

Data for X-Ray Analysis, Volume I, Charts for Solution of Bragg's Equation. W. PARRISH AND B. W. IRWIN. 99 pp. Philips Technical Library, Mount Vernon, New York, 1953. $2.00.

Data for X-Ray Analysis, Volume II, Tables for Computing the Lattice Constant for Cubic Crystals. W. PARRISH, M. G. EKSTEIN, AND B. W. IRWIN. 81 pp. Philips Technical Library, Mount Vernon, New York, 1953. $2.00.

Design for a Brain. W. ROSS ASHBY. 260 pp. John Wiley and Sons, Inc., New York, 1952. $6.00. The book is . . . an attempt to solve a specific problem: the origin of the nervous system's unique ability to produce adaptive behaviour.

Development of the Guided Missile. KENNETH W. GATLAND. 133 pp. Philosophical Library, New York, 1952. $3.75. The author has gathered together all the available facts on the evolution of guided missiles up to the present time and describes their possible future development.

Directory of Secondary Day Schools 1951-1952. MABEL C. RICE. 169 pp. Federal Security Agency. $1.00. Shows accredited status, enrollment, staff, and other data.

Dislocations and Plastic Flow in Crystals. A. H. COTTRELL. 223 pp. Oxford University Press, New York, 1953. $5.00. Brings together the various developments in the theory of dislocations and crystal plasticity in a single coordinated account.

Dynamical Oceanography. J. PROUDMAN. 409 pp. John Wiley and Sons, Inc., New York, 1953. $8.50. The only book in the English language which gives a systematic treatment of the dynamics of the oceans.

Earth, Its Origin, History, and Physical Constitution. Third Edition. HAROLD JEFFREYS. 392 pp. Cambridge University Press, New York, 1952. $13.50. This book began in a series of lectures. Since second edition in 1929, great advances have been made in all branches of geophysics, and great changes have been necessary in the present edition.

Educators Guide to Free Films. Compiled by MARY FOLEY HORKHEIMER AND JOHN W. DIFFOR. 516 pp. Educators Progress Service, Randolph, Wisconsin, 1953. $6.00. This thirteenth annual edition replaces all volumes which have preceded it. It is a complete, up-to-date schedule of free films.

Educators Guide to Free Slidefilms. Compiled and edited by MARY F. HORKHEIMER AND JOHN W. DIFFOR. 185 pp. Educators Progress Service, Randolph, Wisconsin, 1953. This fifth annual edition is a professional, cyclopedic service on slidefilms and slides.

Elasticity in Engineering. ERNEST E. SECHLER. 419 pp. John Wiley and Sons, Inc., New York, 1952. $8.50. Written primarily for engineers working in all fields of structural analysis.

Electric Circuit Theory and the Operational Calculus. Second Edition. JOHN R. CARSON. 197 pp. Chelsea Publishing Company, New York, 1953. $3.95. Course of fifteen lectures given during 1925 at the Moore School of Electrical Engineering of University of Pennsylvania. Second edition with corrections.

Electric Control Systems. Third Edition. RICHARD W. JONES. 511 pp. John Wiley and Sons, Inc., New York, 1953. $7.75. For senior students who have had courses in A-C and D-C machinery, ordinary differential equations, and basic electronics.

Elements of Heat Treatment. GEORGE M. ENOS AND WILLIAM E. FONTAINE. 286 pp. John Wiley and Sons, Inc., New York, 1953. $5.00. Provides a thorough grounding in the basic principles governing the application of heat to alter the mechanical properties of metals.

Essay on Method. C. HILLIS KAISER. 163 pp. Rutgers University Press, New Brunswick, New Jersey, 1952. $3.25. A comparative analysis of the methods of art, science, philosophy, and religion, in order to determine the kinds of problems which can be solved by the methods of each, and the educational emphasis each should receive in our colleges and universities.

Experimental Nuclear Physics, Volume I. Edited by E. SEGRÈ. 789 pp. John Wiley and Sons, Inc., New York, 1953. $15.00. Several authors prepared reasonably complete treatises on a restricted field in which they are quite authoritative.

Fatigue and Fracture of Metals. Edited by WILLIAM M. MURRAY. 313 pp. The Technology Press, Massachusetts Institute of Technology and John Wiley and Sons, Inc., New York, 1952. $6.00. The fourteen papers constituting this volume were presented at a Conference on the Fatigue and Fracture of Metals at the Massachusetts Institute of Technology in June, 1950.

Fatigue of Metals. R. CAZAUD, translated by A. J. FENNER. 334 pp. Philosophical Library, New York, 1953. $12.50. A comprehensive survey of the subject, prepared by one who has made extensive personal research contributions to current knowledge.

Ferroelectricity. E. T. JAYNES. 137 pp. Princeton University Press, Princeton, New Jersey, 1953. $2.00. Intended to serve as a general introduction to the subject of ferroelectricity and guide to the literature, with review of various theories of $BaTiO_3$ that have been published.

Ferromagnetic Properties of Metals and Alloys. K. HOSELITZ. 317 pp. Oxford University Press, London, 1952. $8.00. For postgraduate and industrial research workers in physics, metallurgy, and electrical engineering.

Ferrous Analysis, Modern Practice and Theory. Second Edition revised. E. C. PIGOTT. 690 pp. John Wiley and Sons, Inc., New York, 1953. $12.50. Book of reference both for the practicing analyst and the advanced student.

Fields and Waves in Modern Radio. Second Edition. SIMON RAMO AND JOHN R. WHINNERY. 576 pp. John Wiley and Sons, Inc., New York, 1953. $8.75. Text of intermediate level.

Filter Design Data for Communication Engineers. J. H. MOLE. 252 pp. John Wiley and Sons, Inc., New York, 1952. $7.50. An attempt to supplement [existing textbooks] by providing charts, tables, and formulae which have been selected or constructed so as to lighten the labor of calculation as much as possible.

Financing Adult Education in Selected Schools and Community Colleges. HOMER KEMPFER AND WILLIAM R. WOOD. 27 pp. Federal Security Agency, Office of Education Bulletin No. 8, 1952. $0.15.

Fluid Dynamics, Volume IV. Edited by M. H. MARTIN. 186 pp. McGraw-Hill Book Company, Inc., New York, 1953. $7.00. Proceedings of the Fourth Symposium in Applied Mathematics of the American Mathematical Society held at the University of Maryland, June 22–23, 1951.

From Lodestone to Gyro-Compass. Captain H. L. HITCHINS AND Commander W. E. MAY. 219 pp. Philosophical Library, New York, 1953. $4.75. An introduction to all branches of the subject of compasses.

Fundamentals of Engineering Electronics. Second Edition. WILLIAM G. DOW. 627 pp. John Wiley and Sons, Inc., New York, 1952. $8.50. Primarily a textbook . . . also useful as a reference book for electron tube and electronic circuit engineers.

Fundamentals of Physical Science. Third Edition. KONRAD BATES KRAUSKOPF. 694 pp. McGraw-Hill Book Company, Inc., New York, 1953. In this edition, new sections have been added and changes made to bring many subjects up to date.

Galvani, Commentary on the Effect of Electricity on Muscular Motion. Translated by ROBERT MONTRAVILLE GREEN. 97 pp. Elizabeth Licht, Publisher, Cambridge, Massachusetts, 1953. $4.00. An English translation, along with reproduction of the original illustrations and a translation of Aldini's dissertation.

Geometrical Optics. C. CURRY. 173 pp. Edward Arnold and Company, London and St. Martin's Press, New York, 1953. $4.25. For use in the first and second post-intermediate years.

Gravity Waves. 287 pp. National Bureau of Standards, Circular 521, 1952. $1.75. Proceedings of the National Bureau of Standards Semicentennial Symposium on Gravity Waves held at the National Bureau of Standards on June 18–20, 1951.

Harwell, The British Atomic Energy Research Establishment. Prepared by the Ministry of Supply and the Central Office of Information. 128 pp. Philosophical Library, New York, 1952. $3.75. Story of the work and problems of the Atomic Energy Research Establishment at Harwell from its inception in 1946 to the end of 1951.

How Children and Teacher Work Together. ELSA SCHNEIDER. 24 pp. Federal Security Agency, Office of Education, Bulletin No. 14, 1952. $0.15.

Index—Massachusetts Institute of Technology, Radiation Laboratory Series. KEITH HENNEY. 160 pp. McGraw-Hill Book Compauy, Inc., New York, 1953. $4.50. Index to the twenty-seven monographs in the series.

Industrial Research and Development. 42 pp. Available from Research and Development Board, Department of Defense, Washington 25, D. C.

Influence of the Wash from Bronze on the Weathering of Marble. DANIEL W. KESSLER AND ROSS E. ANDERSON. 11 pp. National Bureau of Standards, Building Materials and Structures Report 137, 1953. $0.15.

International Bibliography on Atomic Energy, Volume 2, Supplement No. 1. 220 pp. Atomic Energy Section, Department of Security Council Affairs, United Nations, New York, 1952. $3.50. This first supplement includes papers published in 1949 and 1950.

Introduction to Mathematical Thought. E. R. STABLER. 268 pp. Addison-Wesley Publishing Company, Cambridge, Massachusetts, 1953. $4.50. To provide a unified and substantial approach to the logical structure of mathematics.

Introduction to Measure and Integration. M. E. MUNROE. 310 pp. Addison-Wesley Publishing Company, Cambridge, Massachusetts, 1953. $7.50. To present measure theory from the abstract or postulational point of view and yet to do this in such a way that the graduate student as well as the expert will find it helpful.

Introduction to Modern Thermodynamical Principles. Second Edition. A. R. UBBELOHDE. 185 pp. Oxford University Press, London, 1952. $4.25. Since the first edition was published [1937], new developments in thermodynamics have reached such widespread importance that an introductory treatment is particularly desirable. New sections have been added.

Introduction to the Foundations of Mathematics. RAYMOND L. WILDER. 305 pp. John Wiley and Sons, Inc., New York, 1952. $5.75. This book grew out of a course in Foundations of Mathematics which author has given at the University of Michigan for over twenty years.

Introduction to the Theory of Functions of a Complex Variable. WOLFGANG J. THRON. 230 pp. John Wiley and Sons, Inc., New York, 1953. $6.50. A text and reference book.

Ionic Processes in Solutions. RONALD W. GURNEY. 275 pp. McGraw-Hill Book Company, Inc., New York, 1953. $6.50. Text directed primarily to graduate students and research workers in the field of electrochemistry.

Journal of the Audio Engineering Society, Volume 1, No. 1. Edited by LEWIS S. GOODFRIEND. 169 pp. Audio Engi-

neering Society, Utica, New York, 1953. $8.00 per year. Published quarterly.

Laboratory Manual of Experiments in Physics. New Sixth Edition. LEONARD ROSE INGERSOLL, MILES JAY MARTIN, AND THEODORE ALTON ROUSE. 286 pp. McGraw-Hill Book Company, Inc., New York, 1953. $4.00. A thorough revision of a comprehensive laboratory manual.

Low Temperature Physics. 291 pp. National Bureau of Standards, Circular 519, 1952. $1.75. Proceedings of the National Bureau of Standards Semicentennial Symposium on Low-Temperature Physics held at the National Bureau of Standards on March 27, 28, and 29, 1951.

Magnetic Circuit—Powder Cores, Ferrites, Permanent Magnet Materials and Miscellaneous Magnetic Materials. A. E. DE BARR. 62 pp. The Institute of Physics, London, 1953. 5s. This monograph is intended for general reading by students in Higher National Certificate in Applied Physics courses or in first two years of a degree course.

Man and His Physical Universe. RICHARD WISTAR. 488 pp. John Wiley and Sons, Inc., New York, 1953. $4.75. An integrated course in physical science.

Mass Spectroscopy in Physics Research. 273 pp. National Bureau of Standards, Circular 522, 1953. $1.75. Proceedings of the National Bureau of Standards Semicentennial Symposium on Mass Spectroscopy in Physics Research held at the National Bureau of Standards on September 6, 7, 8, 1951.

Mathematical Aspects of the Quantum Theory of Fields. K. O. FRIEDRICHS. 272 pp. Interscience Publishers, Inc., New York, 1953. $5.00. Five papers previously printed in *Communication on Pure and Applied Mathematics* are republished in present volume.

Mathematical Theory of Non-Uniform Gases and Notes Added in 1951. Second Edition. SYDNEY CHAPMAN AND T. G. COWLING. 431 pp. Cambridge University Press, New York, 1953. $10.50. An account of the kinetic theory of viscosity, thermal conduction, and diffusion in gases.

Maximum Permissible Amounts of Radio-Isotopes in the Human Body and Maximum Permissible Concentrations in Air and Water. 45 pp. National Bureau of Standards, Handbook 52, 1953. $0.20.

Measurement Techniques in Mechanical Engineering. R. J. SWEENEY. 309 pp. John Wiley and Sons, Inc., New York, 1953. $5.50. Treatment of the principles and techniques of measurement for the performance testing of power equipment.

Mechanics, Part 1: Statics. J. L. MERIAM. 340 pp. John Wiley and Sons, Inc., New York, 1952. $4.00. Integrates the usual pre-engineering background of physics, mathematics, and graphics.

Mechanics, Part 2: Dynamics. J. L. MERIAM. 330 pp. John Wiley and Sons, Inc., New York, 1952. $4.00. Treatment of the theory and application of mechanics.

Mechanics of Materials. Siebert Fairman and Chester S. Cutshall. 420 pp. John Wiley and Sons, Inc., New York, 1953. $5.75. Fundamental book for the average student.

Medieval Science of Weights. ERNEST A. MOODY AND MARSHALL CLAGETT. 438 pp. The University of Wisconsin Press, Madison, 1952. $5.00. Treatises ascribed to Euclid, Archimedes, Thabit ibn Qurra, Jordanus de Nemore, and Blasius of Parma.

Mémoires Sur la Théorie des Systèmes des Équations Différentielles Linéaires. J. A. LAPPO-DANILEVSKY. 204 pp. Chelsea Publishing Company, New York, 1953. $10.00. Volumes I, II, III bound as one volume.

Meson Physics. ROBERT E. MARSHAK. 378 pp. McGraw-Hill Book Company, Inc., New York, 1952. $7.50. A text and reference book.

Metadyne Statics. JOSEPH MAXIMUS PESTARINI. 415 pp. The Technology Press of Massachusetts Institute of Technology and John Wiley and Sons, Inc., New York, 1952. $9.00. This book brings a novel point of view to the relatively mature field of rotating direct-current machinery.

Metallurgical Equilibrium Diagrams. W. HUME-ROTHERY, J. W. CHRISTIAN, AND W. B. PEARSON. 311 pp. The Institute of Physics, London, 1952. 50s. Deals with experimental methods used in determining metallurgical equilibrium diagrams.

Method for Determining the Resolving Power of Photographic Lenses. FRANCIS E. WASHER AND IRVINE C. GARDNER. 27 pp. National Bureau of Standards, Circular 533, 1953. $1.00. This circular supersedes NBS Circular 428.

Methods of Statistical Analysis. Second Edition. CYRIL H. GOULDEN. 467 pp. John Wiley and Sons, Inc., New York, 1952. $7.50. A very complete revision and the introduction of much new material.

Micrometeorology—A Study of Physical Processes in the Lowest Layers of the Earth's Atmosphere. O. G. SUTTON. 333 pp. McGraw-Hill Book Company, Inc., New York, 1953. $8.50. An account of the mathematical physics of the lower atmosphere.

Microwave Spectroscopy. WALTER GORDY, WILLIAM V. SMITH, AND RALPH F. TRAMBARULO. 446 pp. John Wiley and Sons, Inc., New York, 1953. $8.00. To provide for microwave spectroscopists, chemists, physicists, and other scientists a conveniently available source of the information which has been obtained to date through microwave spectroscopy.

Modern College Physics. Second Edition. HARVEY E. WHITE. 823 pp. D. Van Nostrand Company, Inc., New York, 1953. $6.75. Text in standard one-year college physics course required as part of the basic training of students planning to major in one of the physical or life sciences.

Modern Mass Spectrometry. G. P. BARNARD. 326 pp. The Institute of Physics, London, 1953. 50s. This monograph collects together and discusses critically the substantial body of knowledge and technique about the mass spectrometer and its uses.

Noordhoff's Wisbundige Tafels in Five Decimalen. P. WIJDENES, Amsterdam. 269 pp. P. Noordhoff, Groningen, Holland, 1953. Geb. f 8.75. Mathematical tables to five decimal places explained in five languages.

Notes on the Quantum Theory of Angular Momentum. EUGENE FEENBERG AND GEORGE EDWARD PAKE. 56 pp. Addison-Wesley Publishing Company, Cambridge, Mas-

sachusetts, 1953. $2.00. To assist graduate students in reading research papers on atomic, molecular, and nuclear structure.

Ontology. CANON FERNAND VAN STEENBERGHEN, translated by REV. MARTIN J. FLYNN. 279 pp. Joseph F. Wagner, Inc., New York, 1952. $4.50. Written for students who are receiving their first introduction to philosophy.

Our Neighbour Worlds. V. A. FIRSOFF. 336 pp. Philosophical Library, New York, 1953. The author writes on things he knows or has good reason for believing, and there is never any possible confusion between definite knowledge and personal opinion.

Philosophy of Nature. ANDREW G. VAN MELSEN. 253 pp. Duquesne University Press, Pittsburgh, 1953. $4.50. Important problems raised by modern science with respect to the philosophy of nature are treated.

Photoconductivity in the Elements. TREVOR SIMPSON MOSS. 263 pp. Academic Press, Inc., New York, 1952. $7.00. Discusses the various photoconductive and other photoelectric effects in twelve of the elements.

Physical Formulae. T. S. E. THOMAS. 118 pp. John Wiley and Sons, New York, Methuen and Company, Ltd., London, 1953. $2.00. A reference book for students and workers in physics and engineering.

Physics. NOEL C. LITTLE. 648 pp. D. C. Heath and Co., Boston, 1953. $6.00. Introductory college physics course.

Physics, Principles and Applications. Second Edition. HENRY MARGENAU, WILLIAM W. WATSON, AND C. G. MONTGOMERY. 814 pp. McGraw-Hill Book Company, Inc., New York, 1953. $7.50. Engineering-physics text for an introductory physics course. New edition is completely rewritten.

Pile Neutron Research. DONALD J. HUGHES. 386 pp. Addison-Wesley Publishing Company, Cambridge, Massachusetts, 1953. $8.50. The level of presentation is that of a first-year graduate course in physics.

Principles of Color Photography. RALPH M. EVANS, W. T. HANSON, JR., AND W. LYLE BREWER. 709 pp. John Wiley and Sons, Inc., New York, 1953. $11.00. Written by Eastman Kodak scientists, this book presents the theory behind color photography.

Principles of Physical Metallurgy. Third Edition. GILBERT E. DOAN. 331 pp. McGraw-Hill Book Company, Inc., New York, 1953. $5.50. Book presents an account of the behavior of metals under the influence of the operations which are performed upon them in the metal fabricating and manufacturing industries. Completely new edition.

Properties of Metallic Surfaces. 293 pp. Institute of Metals, London, 1953. $5.50. Papers given at Symposium at the Royal Institution, London in November 1952.

Radiant Universe. GEORGE W. HILL. 489 pp. Philosophical Library, New York, 1952. $4.75. New way of looking at natural phenomena, based upon viewing all things in the Universe as consisting solely of radiation.

Radio Frequency Power Measurements. ROALD A. SCHRACK. 16 pp. National Bureau of Standards, Circular 536, 1953. $0.15.

Recordings for Teaching Literature and Language in the High School. ARNO JEWETT. 71 pp. Federal Security Agency, Office of Education, Bulletin No. 19, 1952. $0.25.

Reihenentwicklungen in der Mathematischen Physik. (Series Developments in the Mathematical Physics). JOSEF LENSE. 216 pp. Walter de Gruyter & Company, Berlin. DM 26 Gzl.

Science Facilities for Secondary Schools. PHILIP G. JOHNSON. 38 pp. Federal Security Agency, Misc. No. 17, 1953. $0.25.

Science of Color. Committee on Colorimetry of the Optical Society of America. 385 pp. Thomas Y. Crowell Company, New York, 1953. $7.00. (Text edition, $5.50). For scientists, artists, manufacturers, and students.

Soft Magnetic Materials Used in Industry. A. E. DE BARR. 62 pp. The Institute of Physics, London. 5s. Monograph intended for general reading by students in Higher National Certificate in Applied Physics courses or in first two years of degree course.

Sound, A Physical Text-book. Fifth Edition. E. G. RICHARDSON. 352 pp. Edward Arnold and Company, London, 1953. $5.00. A considerable rearrangement of the text has been made and a considerable quantity of new material has been added.

Stability of Rotating Liquid Masses. R. A. LYTTLETON. 150 pp. Cambridge University Press, New York, 1953. $6.50. Covers those parts of the theory of stability of rotating gravitating liquids that seem to be of primary importance in determining the evolution of such systems.

Statistical Summary of Education 1949-50, Chapter 1. ROSE MARIE SMITH. 52 pp. U. S. Department of Health, Education and Welfare. $0.20. One of five chapters printed separately as part of the Biennial Survey of Education in the United States, 1948–50.

Storage Tubes and Their Basic Principles. M. KNOLL AND B. KAZAN. 143 pp. John Wiley and Sons, Inc., New York, 1952. $3.00. To explain in concise form the fundamental operation of the different types of storage tubes and to provide this information in an easily accessible manner.

Stress Waves in Solids. H. KOLSKY. 211 pp. Oxford University Press, New York, 1953. $5.00. Summary of the classical theory . . . and considers how this theory can be extended to solids which are not perfectly elastic.

Student Deferment in Selective Service. M. H. TRYTTEN. 140 pp. University of Minnesota Press, Minneapolis, 1952. $3.00. Explains the bases for the deferment policy's adoption, outlines the criteria and methods of deferment, and describes the college qualification test used.

Superconductivity. Second Edition. D. SHOENBERG. 253 pp. Cambridge University Press, New York, 1952. $6.00. Complete revision of first edition published in 1938.

Tables of the Bessel Functions $Y_0(x)$, $Y_1(x)$, $K_0(x)$, $K_1(x)$, $0 \leq x \leq 1$. 60 pp. National Bureau of Standards, Applied Mathematics Series 25. $0.40.

Teaching of General Biology in the Public High Schools of the United States. W. EDGAR MARTIN. 46 pp. Federal Security Agency, Bulletin No. 9, 1952. $0.20.

Textbook of Engineering Materials. MELVIN NORD. 518 pp. John Wiley and Sons, Inc., New York, 1952. $6.50. One-semester course for all engineering students at the lower sophomore or upper freshmen level.

Theory of Elasticity and Plasticity. H. M. WESTERGAARD. 176 pp. Harvard University Press, Cambridge and John Wiley and Sons, Inc., New York, 1952. $5.00. Introduction to the theories of elasticity and plasticity. Written from point of view of the engineer though the treatment is entirely theoretical.

Theory of Homogeneous Turbulence. G. K. BATCHELOR. 197 pp. Cambridge University Press, New York, 1953. $5.00. Monograph makes available in permanent form the great advances made in the subject of homogeneous turbulence in fluids since 1935.

Thermionic Vacuum Tubes and Their Applications. Sixth Edition. W. H. ALDOUS AND SIR EDWARD APPLETON. 160 pp. John Wiley and Sons, Inc., New York, 1952. $2.00. A radical revision of the earlier text, done by W. H. Aldous.

Thermodynamics of the Steady State. K. G. DENBIGH. 103 pp. John Wiley and Sons, Inc., New York, and Methuen & Company, London, 1951. $1.75. Writing of this monograph developed from certain studies on the theory of open reaction systems.

Vacuum-Tube Oscillators. WILLIAM A. EDSON. 476 pp. John Wiley and Sons, Inc., New York, 1953. $7.50. Treatment of the many factors which affect the behavior of vacuum-tube oscillators.

Vienna Circle—The Origins of Neo-Positivism. VICTOR KRAFT. 209 pp. Philosophical Library, New York, 1953. Translated from the German "Der Wiener Kreis" by Arthur Pap. For American readers the detailed discussions of articles in the somewhat inaccessible periodical *Erkenntnis*, major organ of publication of the Circle, ought to be particularly valuable.

U. S. National Commission for UNESCO. 30 pp. Informal report of the United States delegation to the seventh session of the General Conference of UNESCO, November-December 1952, Paris.

Waves and Tides. R. C. H. RUSSELL AND D. H. MACMILLAN. 348 pp. Philosophical Library, New York, 1953. $6.00. This book, arranged in two parts, really consists of two distinct books.

Youth—The Nation's Richest Resource, Their Education and Employment Needs. 54 pp. Federal Security Agency. $0.20. A Report prepared by the Interdepartmental Committee on Children and Youth of the Federal Government.

Practical Aids for Teachers of Physics

Compact batteries for C-bias as used in portable equipment generally prove unsatisfactory in the physics laboratory. They have a short life especially when not given proper treatment, since their energy capacity is low.

A number of the following units have been built both in our home laboratory and at our present assignment. They have proved very popular and satisfactory. Five large 1½-volt flashlight cells are inserted end to end in a channel cut into a suitable board such as a "2×4." A similarly cut board covers the cells in a sandwich-like construction—the two halves being held together by screws. End pieces are screwed on with spring connectors making contact with the respective ends of the battery. A volume control of 10 000 ohms with switch to remove the drain on the cells when not in use, is connected as a potential divider and mounted on the top board by drilling a recess in the back of the board. A voltmeter of the panel type is also mounted flush on the top board. A simple toggle-type reversing switch with terminals completes the construction. This source provides C-bias from $-7\frac{1}{2}$ to $+7\frac{1}{2}$ volts for the normal shelf life of the cells. To replace the cells, one end is removed and new cells inserted. (Contributed by GEORGE A. DONOVAN, *Colorado A. and M. College*, and LOUIS R. WEBER, Fulbright Lecturer, *College of Arts and Sciences*, Baghdad, Iraq.)

A well-illustrated booklet of 24 pages describing Naval establishments conducting scientific research and development programs has been issued by the Potomac River Naval Command, which covers the metropolitan Washington, D. C. area and adjacent areas in the vicinity of the Potomac River and Chesapeake Bay. Presumably a supply of these may be obtained from the Executive Secretary, Board of Examiners for Scientific and Technical Personnel of the Potomac River Naval Command, Building 37, Naval Research Laboratory, Washington 25, D. C., since this is the only complete address in the booklet.

The Editor's office has received a publication, "Selected Science Teaching Ideas of 1952," edited by R. Will Burnett and published by the National Science Teachers Association, Washington, D. C. It is an impressive 60-page, illustrated pamphlet, containing 15 chapters covering the range from "The Selection and Training of Future Scientists" to "Our Astronomy Unit." The price is $1.50 each, available from the National Science Teachers Association, 1201 Sixteenth Street, N. W., Washington, D. C. Members of the NSTA are quoted a special price one-third less.

An automatic pick-up tweezer in stainless steel may prove useful in the repair of delicate laboratory instruments. It works on the same principle as a Swedish sugar tongs but is now fairly common in this country. It sells for $2.25 and is marketed by Win Sales Company, Department 12T, P. O. Box 257, Forest Hills, New York.

Improvisations

PROFESSOR LOUIS R. WEBER, *Colorado A. and M. College*, Fort Collins, Colorado, spent the year 1952–53 as Fulbright Lecturer in the College of Arts and Sciences, Baghdad, Iraq. He found himself much less liberally supplied with demonstration equipment and convenient storage rooms than in the U. S. He, therefore, improvised many lecture demonstrations in which student participation was essential. Here are some of his suggestions:

1. *Equilibrium.* In the first lecture, I encourage students by suggesting that they know more physics than they realize. As proof of this, a student is asked to come to the door at the front of the lecture room and stand with his right shoulder and right foot against the door frame. Now

the student is directed to raise his left foot. He will discover to his chagrin that he cannot do so and maintain his equilibrium. However, I generally point out that the student has no difficulty lifting his feet as he walks back to his seat. Although some students will explain this by describing how the weight is shifted back and forth over the leg that supports the body, the actual proof of the shifting was nicely explained by my own daughter when she sat in my class. She had noticed that if two people are walking 180° out of step, the inner arms of each will collide on alternate steps.

2. *Mass.* Select two students having a large difference of mass. Another student is blindfolded and asked to push first on the back of one student, then on the other. He then tells the class, from this experience, which one of the students has the greater mass.

3. *Newton's Third Law.* Extend a book to a student and ask him to exert a force of 32 poundals on it. As he pulls on the book, let it slip through your hand. The force, of course, will be practically zero. On the next trial, hold firmly to the book. The student can now exert the required force.

4. *Centripetal and Centrifugal Force.* The student walks rather quickly in front of you across the lecture room. Grasp his hand and constrain him to deviate from his straight path. Stop the action and point out the fact that, whereas the centripetal force is exerted by the lecturer on the student, the student exerts a centrifugal force on the lecturer. This demonstration can be varied with different velocities and students of different masses.

5. *Surface Tension.* Interlink your arms firmly with a student on each side of you. Now walk three abreast towards the lecture door. It is now obvious that you cannot pass through the door. Loosen the arm linkage and walk through easily. This illustrates very vividly why water will pass through small holes when the surface tension is lowered.

6. *Torque.* Have a student grasp the back edge of the lecture door as it stands open or he may pull on the door knob in a direction that lies in the plane of the door. (He has probably never pulled on the door in this manner and the class is always surprised to see such vigorous movement with no resulting torque.) Of course, when he pulls on the knob in the direction perpendicular to the plane of the door, he rotates the door.

New Members of the Association

The following persons have been made members or junior members (*J*) of the American Association of Physics Teachers since the publication of the preceding list [Am. J. Phys. **21**, 654 (1953)].

Bernardes, Newton, Instituto Tecnologico de Aeronautica, Sao Jose Dos Campos, Sao Paulo, Brazil

Brody, Selma Blazer, University of Connecticut, Storrs, Connecticut.

Dees, Bowen C., 3736 Yuma Street, N. W., Washington 16, D. C.

Lane, William Stephen, P. O. Box 23, Burton, Washington.

Long, Pauline K., 4222 Fourth Ave., So., Birmingham 6, Alabama.

Marean, John H., 1218 Humboldt, Reno, Nevada.

Therese, Sister M. Catherine, C.S.J., 1219 Avenue O, Brooklyn 30, New York.

Welty, Clarence Porter, 3818 Torrence Ave., Hammond, Indiana.

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RECENT MEETINGS

Chesapeake Section

The fall meeting of the Chesapeake Section of the American Association of Physics Teachers was held at Rowland Hall, Johns Hopkins University, Friday, November 14, 1952. A social hour preceded the meeting. There was a panel discussion at the meeting on the topic **Getting qualified students into physics** with some lively audience participation afterward. President ROBERT R. MEIJER of *George Washington University* presided. The speakers were: MARY E. BATISTE, *National Science Teachers Association;* JASTRO LEVIN, *Baltimore Polytechnic Institute* and *Ford Foundation Fellow;* JOHN S. THOMSEN, *Johns Hopkins University Institute for Cooperative Research.*

Dr. STANLEY HANNA and Dean RICHARD T. COX discussed the laboratory equipment and experiments that were observed on the inspection tour that followed the meeting.

J. ROSS HEVERLY
Secretary-Treasurer

Chesapeake Section

The spring meeting of the Chesapeake Section, American Association of Physics Teachers, was held Saturday forenoon and afternoon, April 11, 1953, in Corcoran Hall, George Washington University, Washington, D. C. The retiring President, ROBERT R. MEIJER, formerly with *George Washington University*, but now with *Bendix Aviation Corporation*, presided.

PAUL W. BOWMAN, acting coordinator of the University's scientific activities, delivered the address of welcome.

The invited papers were as follows:

1. The work of the National Science Foundation. PAUL E. KLOPSTEG, Associate Director of the *National Science Foundation* and President of the American Association of Physics Teachers.

2. Semiconductors. WAYNE SCANLON, *Naval Ordnance Laboratory.*

3. The past and future of the sun. GEORGE GAMOW, *George Washington University.*

The ten-minute contributed papers were as follows:

1. **How to confuse dimensions in mechanics,** JOHN S. THOMSEN, Institute for Cooperative Research, *Johns Hopkins University.*

2. **Microwave measurement of variations in the atmospheric index of refraction.** GEORGE BIRNBAUM, *National Bureau of Standards.*

3. **Microwave spectroscopy of gases.** R. G. NUCKOLLS, *National Bureau of Standards.*

4. **An electrostatic bird.** JOHN H. REAVES, *National Bureau of Standards* (apparatus prepared at American University).

5. **A small magnetron.** THOMAS B. BROWN, *George Washington University.*

6. **A laboratory experiment with the actinoscope.** EDWIN P. HEINRICH, *Sidwell Friends School* and *American University.*

7. **A laboratory experiment on the Maxwellian distribution of thermionic electrons.** ROBERT R. MEIJER (read by title only).

The report on the Annual Meeting of the AAPT at Cambridge which had been prepared by our representative, G. EMMETT C. KAUFFMAN, formerly with the *University of Delaware* but now with Dupont, was read by THOMAS B. BROWN of *George Washington University.*

The dismissal of DR. ASTIN as Director of the National Bureau of Standards and the concurrent threat to the capabilities and effectiveness of the Bureau of Standards was brought up for discussion as a matter in which we as scientists were deeply concerned. After some discussion as to the proper and most effective way to express the Section's concern and alarm at Secretary of Commerce Weeks' dismissal of Dr. Astin as Head of the National Bureau of Standards and his concurrent attack upon the integrity and objectivity of the scientists at the National Bureau of Standards, it was decided that the Executive Committee should be empowered to use their judgment in the conveying of the disapproval of the Section.

The Executive Committee shortly thereafter agreed upon the following wording for a telegram which was sent to PRESIDENT EISENHOWER:

> The Chesapeake Section of the American Association of Physics Teachers wishes to express its deep concern and alarm at the summary dismissal of Dr. Astin as Director of the Bureau of Standards and at the doubt that was thereby cast on the objectivity, integrity, and competence of the scientists at the Bureau. We strongly endorse a full and impartial investigation of the charges that have been made against the objectivity of the Bureau because we feel that the contribution of the Bureau to the national welfare is dependent upon a continued tradition of disinterested scientific appraisal free from political and commercial pressure.
>
> Executive Committee
> Chesapeake Section A. A. P. T.
> J. R. HEVERLY, *Secretary*

This telegram, sent to President Eisenhower and criticizing the action of SECRETARY WEEKS, was referred to Secretary Weeks for reply. Reply was made by a special assistant to the Secretary of Commerce. It consisted of the statements made by Weeks and Astin and an article from Fortune magazine. This article quoted the erroneous Senate committee report that the M. I. T. tests gave complete support to the manufacturers of ADX_2 and made little of the crucial point made by the National Bureau of Standards that under conditions encountered in the normal use of automobile storage batteries ADX_2 was of no value.

J. ROSS HEVERLY
Secretary-Treasurer

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